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PERSPECTIVE

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Social controversy belongs in the climate science classroom

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Scientists, educators and stakeholders are grappling with how to best approach climate change education for diverse audiences, a task made difficult due to persistent social controversy. This Perspective examines how sociocultural learning theories can inform the design and implementation of climate change education experiences for learners with varied understandings of and attitudes towards climate change. The literature demonstrates that explicitly addressing learners' social and community experiences, values and knowledge supports understandings of and increased concern about climate change. Science learning environments that situate climate change in its social context can support conceptual understandings, shift attitudes and increase the participation of diverse communities in responding to climate change. Examples are provided of successful programmes that attend to social dimensions and learners' previous experiences, including experiences of social controversy.

There is perhaps no sentence as frustrating or baffling to those working in climate-related fields as: 'I don't believe humans are influencing climate change.' What is the appropriate response to such a statement? One could begin by enumerating the lines of evidence that support the scientific consensus of anthropogenic climate change, or one could choose to tackle the problematic use of the word 'believe'. Is this a conversation for a science class or is another arena more fitting? While one may wish to leave social aspects — particularly controversies — out of science class, an 'objective' presentation of evidence may not be the most effective approach. Research on science learning emphasizes that focusing on conceptual understanding is not enough, and situating science in its social context promotes deeper learning[1,2]. As scientists and educators continue to collaborate to support climate change learning, it is important to provide opportunities for learners to voice and examine the understandings they bring with them to a classroom, including those that are in conflict with consensus understandings.

Science learning involves more than just facts

Consensus research on how people learn science indicates that scientific content knowledge is only one factor in developing scientific expertise and using it in everyday life[1–3]. Science learning requires negotiating economic, cultural, moral and political values and knowledge[4]. Despite this, climate change's complex social context may be seen as outside the purview of science class and excluded from coursework. This exclusion may be due to a desire to differentiate scientific evidence and social values and opinions, to keep from being perceived as an advocate, or stay within one's area of expertise. We argue that despite these challenges, attending to sociocultural foundations of learning deepens holistic climate science learning. Here we particularly address the inclusion of social context in formal school environments; however, the principles discussed are applicable across learning environments, such as outreach talks, museum exhibits[5] and university classes[6].

The past decade has seen a proliferation of curricular development efforts and funding opportunities in climate change education (CCE). These efforts will probably increase with the inclusion of climate change and sustainability in the United States' 2013 Next Generation Science Standards (NGSS) for school-age education[7]. These standards are three-dimensional performance expectations that include disciplinary core ideas, science and engineering practices, and cross-cutting concepts. The NGSS include climate science core ideas, relevant practices (for example, modelling) and cross-cutting concepts (for example, systems thinking, stability and change). The theoretical framework that guided the writing of the NGSS emphasizes that the diverse social and cultural experiences students bring to the classroom are assets for learning, and supports pedagogical practices that draw on students' everyday experiences and values[8]. It further underscores that students learn new material in the context of what they know, and that personal interest, experience and enthusiasm plays a key role in determining future participation in science.

At present, climate change appears in few state standards, leaving numerous districts, schools and teachers grappling with CCE for the first time. In the United States and the United Kingdom, many teachers can expect students to arrive in class armed with evidence contradicting scientific content[9–13]. This leaves educators with a dilemma as to whether they should address the controversy head-on in class or present only 'the science' in the hope that the lines of evidence or 'right' information will displace contrary arguments. However, even the most seemingly logical presentation of evidence may not alter perceptions and understandings, as learners' initial values and beliefs inform how any information presented in class is understood. This is true whether or not they are explicitly addressed in the classroom[1,2,14,15]. Thus, even when presented with data that scientists find convincing, learners may not similarly value or understand them, especially if the data does not resonate with their previous knowledge and experience, or the sources and types of knowledge they value.

This is because learners make sense of new information in the context of what they already know, and reasoning, problem solving and interpretation of information is informed by previous experience[3,16]. Learners attempt to reconcile new concepts with their initial conceptions in ways that may or may not align with the instructional intent. For example, if a student who conceptualizes the Earth as flat is told that the Earth is round, the student may reconcile their new and previous understandings by conceptualizing the Earth as round like a pancake instead of round like a sphere[3].

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For CCE, previous experiences of climate change may include controversy, and these experiences of climate change and social controversy will enter the classroom whether or not social factors are mentioned. Thus, scientific values and norms are not the only ones at play in science learning. For example, the Vostok ice-core temperature and carbon dioxide record may be presented to demonstrate the difference between present and past atmospheric carbon dioxide concentrations. However, climate sceptics sometimes use the data to support the claim that humans are not influencing changes in the climate, as temperatures begin to increase ~800 years before carbon dioxide levels during glacial termination periods[17]. Understanding why one argument is more scientific than the other requires an understanding of how scientists make sense of data and use them to support claims. Students have experiences not only with the data, but also with how various groups use the data to construct arguments. Failing to surface these previous understandings and experiences, including social values and perceptions informed by popular culture and media, leaves learners with conflicting ideas and without an opportunity to resolve tensions between their previous experiences and those in the classroom.

Climate change experiences are not limited to classrooms, but occur throughout a lifetime, across all contexts, and are informed by the cultural values and norms of the communities to which a learner belongs[4]. From this sociocultural perspective, all learning is mediated by participation in various cultural groups[18]. Learning is understood not just as an accumulation of facts, but as changing ways of participating in cultural practices[15] or deepening participation within a community[19,20]. When an individual participates in multiple communities (for example, a conservative home and a climate science class) or is learning how to become more involved in a new community (for example, becoming a scientist), that individual must navigate between the practices, traditions and values of the multiple communities to which they belong. This navigation in and out of scientific communities has been implicated as a barrier to broadening the participation of diverse groups in science and is challenging even without an added layer of social controversy[14,21,22]. If learners' social and cultural experiences are in conflict with scientific knowledge or are undervalued, learners may not participate fully in the science learning environment[23].

Sociocultural approaches to teaching science

Educators use 'culturally relevant teaching' or 'culturally responsive teaching' (CRT) to build bridges between various contexts (home, school and so on) by leveraging students' experiences, values and knowledge[24–28]. A CRT approach to CCE can connect learners' in- and out-of-school lives by drawing on the knowledge and experiences of students as resources for deepening scientific expertise, framing the instruction in ways that are personally relevant to students, aligning instruction to learners' values and attending to social dimensions of learning. Although research has shown that CRT can deepen student understanding of science in other areas, so far little research has been conducted on culturally relevant CCE. Below, we describe existing projects that take a CRT approach to CCE and outline examples of how it improves students' understanding in other science areas to provide insight into implementation of it for CCE.

Student experience as a learning resource

The knowledge and experience from everyday life practices that learners bring to new situations can serve as valuable resources for learning. Drawing on learners' everyday knowledge, practices and experiences can engage and support students, including those who have previously underperformed in school. For example, researchers studied how a biology curriculum connected science content to students' lives by creating opportunities for students to demonstrate their expertise in the knowledge and practices of their families, communities, peers and pop culture[29,30]. Positioned as 'experts', student participants were able to engage with and take ownership of scientific content. One student in a New York City classroom was able to draw on her knowledge of growing potatoes with her grandma in Puerto Rico to understand how potatoes grew in her science classroom experience. Her family experience helped her make sense of vegetative propagation as presented in a school science laboratory and develop a deeper conceptual understanding. Having made these connections between home and school life, she decided to extend the classroom experiment on her own at the end of the laboratory session.

Eliciting learners' previous experiences also allows them the opportunity to reconcile inconsistencies in their experiences. In a study of Haitian American students, learners noticed a seeming discrepancy between their personal experiences of water shortages in Haiti (how 'water is wasted') with the scientific concept of the hydrological cycle in which there is 'always the same amount of water as there was a long time ago'.[31] Through discussions in class that elicited students' knowledge of water abundance, learners resolved these conflicting ideas. Instead of using a top-down approach in which students were merely told about the hydrological cycle, surfacing what students already knew about water allowed for them to engage with the topic in a personal way and integrate knowledge from two contexts. Similar conversations could occur for topics central to CCE, such as the carbon cycle. For example, students may have heard that we are 'using up' or 'running out of' carbon by burning fossil fuels, and may not consider the fate of the carbon that makes up these fuels, perhaps thinking that it simply goes away or disappears. This can be used as a starting place for a discussion of conservation of mass and what happens to fossil fuel carbon when it is burned. One can make connections between burning of fossil fuels as a source of carbon dioxide to the atmosphere and the cycling of this carbon dioxide through interactions with other carbon reservoirs.

Students' perceptions of climate change are similarly informed by family, community, peers and popular media. Something as simple as having a discussion or giving a short survey can reveal not only students' initial conceptual understandings, but also the interests, values, attitudes and relevant home and community practices that can be leveraged in a classroom to support holistic climate change learning. Initial understandings both provide a starting place for instruction and reveal inaccurate student conceptions (for example, that the ozone hole is the mechanism for global warming)[32–35]. Some students may have already begun to notice changes in their own lives, or may have experiences, such as with weather, that can rightly or wrongly reinforce or contradict perceptions of changes in climate[36]. Educators can use these experiences of weather and connect them to longer-timescale climate change. For example, students could measure temperature and precipitation in their home or school over a few weeks or a month, and analyse the variability in their data. The data could be compared with annual and decadal local records to investigate variability and trends on various timescales. By uncovering initial perceptions and conducting these kinds of exploration, students may begin to resolve tensions between their lived experiences of weather variability and climate change and gain a deeper understanding of the difference between weather and climate.

Popular media can also inform initial perceptions, and media depictions have been implicated as propagating the perception of controversy due to the emphasis on uncertainty, giving equal attention to 'both sides' and the way it is framed (for example, as a crisis or a hoax)[37,38]. In class, one can examine media portrayals, discuss the frames used and compare the evidence used by politicians or reporters to that of scientists. One can examine what, if any, scientific content is presented in the media and if it is used appropriately.

For learners who either do not think that climate change is happening or do not think it is human-influenced, omitting discussions of initial ideas may increase discontinuity between everyday and school experiences, and provide barriers for class participation. Instead of leaving students to wrestle with conflicting ideas, the evidence and arguments that students bring with them can be carefully examined in the classroom with the support of an instructor. However, having students bring evidence that challenges the scientific consensus into the classroom should not be confused with putting the students' evidence and consensus scientific evidence on equal footing, presenting the science as controversial, or implementing a structured debate about the science. One lesson learned from evolution education literature is that students gain a deeper understanding of science when allowed to explore social ideas around evolution, but not when the science is presented as controversial[39,40]. Just as a student's initial conflation of weather and climate would not be treated as correct in class, student ideas that are in conflict with the science can be acknowledged and refined through instruction.

In our own work, we have described how CRT can support deeper conceptual understandings and change attitudes of high-school freshmen who were initially uncertain that the climate was changing, did not think any possible changes were human-influenced and did not think it was an important topic[41]. Students participated in a culturally responsive biology curriculum on the ecological impacts of climate change that elicited initial understandings of and attitudes from popular media and the home, and included student-directed research into local and global ecological impacts. One conservative, self-identified Republican student initially espoused pundit Limbaugh's view of climate change as a conspiracy. Over time, the student changed his mind, due in part to his identification as someone who could 'see all sides' of an argument, unlike Rush Limbaugh, who the student characterized as having a more narrow perspective. Instructors framed the student's scepticism as an asset, connecting his analytical practices to scientific critical thinking. Another student chose to research Milankovitch cycles, thinking these would show that natural variability was the cause of current changes in climate. Through analysis of the data, he realized that the science did not support his initial understanding. Rather than dismissing his ideas as problematic, the instructor leveraged them to support expertise in scientific content knowledge and evaluating and using evidence to construct scientific arguments. Without eliciting their existing knowledge and reframing their skills as scientific, these students would probably not have had as deep learning gains.

Student interest and values as resources

A key characteristic of CRT is personal relevance, a challenge for CCE as many view climate change as a distant threat, both in timescale and geographically[11]. Student-directed approaches can increase relevance by focusing on issues that are of interest to students, including local and community impacts, and connecting to learner and community values.

Examining local impacts in addition to global changes can increase climate change's personal relevance[42–44]. Given that impacts vary regionally, some efforts have sought to connect to changes specific to particular places and cultural groups. For example, a team of high school teachers, climate scientists and educators is working to develop experiences in tribal communities in Idaho that embed climate science explorations in the history of local people and their surroundings[42]. Learners have the opportunity to examine impacts on culturally significant practices, such as changes in fisheries, wildlife and forests. This strategy engages students through the examination of impacts on things they care about, and can empower students to take action in their local community. Positioning learners' knowledge, interests and values as resources resonates with the Intergovernmental Panel on Climate Change's call for greater inclusion of local, indigenous knowledge in the construction of climate science[45]. The oral traditions of native communities contain valuable historical climate and ecosystem records that complement instrumental records, and place changes in the 'context of a human landscape' in which they occur[44]. These valuable records are intertwined with the values, interests and lives of human communities, but are not often privileged in scientific knowledge construction or science education.

Programmes implemented by the National Wildlife Federation similarly support a focus on local issues[41]. These programmes target leaders of hunting and angling organizations, largely conservative groups. The National Wildlife Federation found that focusing on local examples, habitat and wildlife, and opportunities for participants to discuss their own experiences and observations were most effective in shifting attitudes towards climate change and increasing advocacy.

Connecting to community values can also increase personal relevance. The informal (out-of-school) learning community has seen success connecting to audiences' values and interests[43,46,47]. Interfaith Power and Light, a multi-faith environmental conservation organization, who are aligned to and emphasize faith doctrine and values of environmental stewardship and eco-justice. They found that connecting to communities through their "hearts rather than solely through their heads" was effective in supporting concern and advocacy[43]. Zoos and aquaria likewise target audience interests to increase engagement in climate change[5,47]. Surveys of zoo visitors by the Climate Literacy Zoo Education Network suggest that personal connections to animals and nature and concern about climate change are correlated to frequency of zoo visits for visitors of all political affiliations (given that zoo audiences are self-selected, a causal relationship could not be determined)[47]. Identifying and aligning with community and personal values has the potential to engage those who might otherwise be unconcerned.

Social positioning

How individuals make decisions about socio-scientific issues is informed by not only scientific information, but also societal conversations around the issue[48]. The ways that issues such as climate change are framed in society are used to construct arguments for or against particular social decisions. Individuals frame issues in ways that align with their social groups, making social identification particularly important when considering responses to climate change[49]. Research suggests that cultural cognition is the dominant mechanism of climate change risk assessment, implying that identification with particular groups is more important than individual scientific knowledge[50]. As others have noted, the importance of the social dimensions does not negate the importance of robust scientific content understanding[51]. This is not an 'either/or' issue, but a 'both/and' issue, as the social and scientific pieces are intertwined in decision-making.

Relationships and social interactions are further important, as family and friends are the most trusted source of information for many who do not think humans are influencing climate change and/or are not concerned about it[9]. Relationships are key for all areas of learning, and teachers have been shown to be the dominant influence on student achievement in a class setting[52]. In CRT, instructors form 'fluid and equitable' relationships with students that allow diverse students to succeed by supporting cultural congruity across learner experiences[25].

The social controversy as an educational opportunity

Few sciences are as integrally intertwined with society as climate change. Humans seek to understand changes in climate while societies shape, and are shaped, by those changes. Social controversies such as climate change can provide opportunities for learning how to evaluate and use scientific evidence, deal with socially or politically relevant topics, and develop an "integrated understanding of scientific issues across the numerous contexts in which they [learners] experience them"[53]. Attending to social context allows students to both increase their proficiency in important scientific practices and develop a greater understanding of how science relates to societal concerns. While students, teachers and scientists have much to gain by addressing the social controversy in the classroom, more pedagogical supports and curricular tools are needed for classroom implementation.

Whether or not we draw on learners' previous understandings of climate change and their values and ideas about addressing impacts, these scientific, personal and social experiences with climate change will be present in the classroom. Rather than seeing controversies as something to be feared or relegated to a non-science class, we should instead view this as an opportunity to foster deeper science learning and to engage students in exciting, cutting-edge science. With CCE, we have the opportunity to further interrogate social learning processes and move the science learning literature forward. As scientists and educators, we need to continue to investigate how best to build these bridges for students with diverse previous experiences with climate change and apply this research to practice as we continue to develop CCE experiences.

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References

1. National Research Council *Taking Science to School: Learning and Teaching Science in Grades K-8* (eds Duschl, R. A., Schweingruber, H. A. & Shouse, A. W.) (The National Academies Press, 2007).
   This is a report of consensus research on science learning that examines the multiple dimensions or 'strands' of science learning, theoretical foundations, pedagogical practice, assessment and diversity in science.
2. National Research Council *Learning Science in Informal Environments: People, Places, and Pursuits* (eds Bell, P., Lewenstein, B., Shouse, A. W. & Feder M. A.) (The National Academies Press, 2009).
   This report on consensus research on science learning in out-of-school environments extends the dimensions of science learning and discusses the theory and practice of learning in informal environments.
3. Bransford, J. D., Brown, A. L. & Cocking, R. R. (eds) *How People Learn: Brain, Mind, Experience, and School* (The National Academies Press, 2000).
4. Banks, J. A. *et al. Learning In and Out of School in Diverse Environments: Life-long, Life-wide, Life-deep* (The LIFE Center and the Center for Multicultural Education, Univ. Washington, 2007).
5. Grajal, A. & Goldman, S. R. *Climate Change Education: A Primer for Zoos and Aquariums* (Chicago Zoological Society, 2012).
6. National Research Council *Climate Change Education in Formal Settings, K-14: A Workshop Summary* (rapporteur Beatty, A.) (The National Academies Press, 2012).
7. NGSS Lead States *Next Generation Science Standards: For States, By States* (The National Academies Press, 2013).
8. National Research Council *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (eds Quinn, H., Schweingruber, H. & Keller, T.) (The National Academies Press, 2011).
9. Maibach, E., Roser-Renouf, C. & Leiserowitz, A. *Global Warming's Six Americas 2009: An Audience Segmentation Analysis* (Yale Project on Climate Change Communication, 2009). **Based on survey results of the US public, this analysis identifies six different audiences for climate change communication defined by their understandings of and attitudes towards climate change.**
10. Kohut, A., Doherty, C., Dimock, M. & Keeter, S. *Little Change in Opinions About Global Warming Increasing Partisan Divide on Energy Policies* (Pew Research Center, 2010).
11. Leiserowitz, A., Maibach, E., Roser-Renouf, C., Feinberg, G. & Howe, P. *Climate Change in the American Mind: Americans' Global Warming Beliefs and Attitudes in April 2013* (Yale Project on Climate Change Communication, 2013).
12. McCright, A. M. & Dunlap, R. E. The politicization of climate change and polarization in the American public's views of global warming. *Sociol. Quart.* **52,** 155–194 (2011).
13. Pidgeon, N. Public understanding of, and attitudes to, climate change: UK and international perspectives and policy. *Clim. Policy* **12,** S85–S106 (2012).
14. Nasir, N. S., Rosebery, A. S., Warren, B. & Lee, C. D. in *The Cambridge Handbook of the Learning Sciences* (ed. Sawyer, R. K.) 489–504 (Cambridge Univ. Press, 2006).
15. Rogoff, B. *The Cultural Nature of Human Development* (Oxford Univ. Press, 2003).
16. DiSessa, A. A. in *The Cambridge Handbook of the Learning Sciences* (ed. Sawyer, R. K.) 265–281 (Cambridge Univ. Press, 2006).
17. Cailon *et al.* Timing of atmospheric CO_2 and Antarctic temperature changes across Termination III. *Science* **299,** 1728–1731 (2003).
18. Vygotsky, L. S. *The Collected Works of L. S. Vygotsky: Problems of General Psychology Including the Volume Thinking and Speech* Vol. 1 (trans. Minick, N.) (Plenum, 1987).
19. Lave, J. & Wenger, E. *Situated Learning: Legitimate Peripheral Participation* (Cambridge Univ. Press, 1991).
20. Wenger, E. *Communities of Practice: Learning, Meaning, and Identity* (Cambridge Univ. Press, 1998).
21. Aikenhead, G. S. Science education: border crossing into the subculture of science. *Stud. Sci. Educ.* **27,** 1–52 (1996).
22. Stanley, W. B. & Brickhouse, N. W. Teaching sciences: the multicultural question revisited. *Sci. Educ.* **85,** 35–49 (2001).
23. Calabrese Barton, A. & Yang, K. The culture of power and science education: learning from Miguel. *J. Res. Sci. Teach.* **37,** 871–889 (2000).
24. Ladson-Billings, G. *The Dream-Keepers: Successful Teachers of African American Children* (Jossey-Bass, 1994).
    This book profiles eight classroom teachers and examines their culturally responsive teaching practices.
25. Ladson-Billings, G. But that's just good teaching! The case for culturally relevant pedagogy. *Theor. Pract.* **34,** 159–165 (1995).
26. Ladson-Billings, G. Toward a theory of culturally relevant pedagogy. *Am. Educ. Res. J.* **32,** 465–491 (1995).
27. Tsurusaki, B, K., Calabrese Barton, A., Tan, E., Koch, P. & Contento, I. Using transformative boundary objects to create critical engagement in science: a case study. *Sci. Educ.* **97,** 1–31 (2013).
28. Gay, G. *Culturally Responsive Teaching: Theory, Research & Practice* (Teachers College Press, 2000).
29. Calabrese Barton, A. & Tan, E. Funds of knowledge and discourse and hybrid space. *J. Res. Sci. Teach.* **46,** 50–73 (2009).
30. Calabrese Barton, A., Tan, E. & Rivet, A. Creating hybrid spaces for engaging school science among urban middle school girls. *Am. Educ. Res. J.* **45,** 68–103 (2008).
31. Warren, B. & Roseberry, A. S. in *Teaching Science to English Language Learners: Building on Students' Strengths* (eds Rosebery, A. S. & Warren, B.) 39–50 (National Science Teachers Association Press, 2008).
32. Bostrom, A., Morgan, M. G., Fischhoff, B. & Read, D. What do people know about global climate change? 1. Mental models. *Risk Anal.* **14,** 959–970 (1994).
33. Boyes, E. & Stanisstreet, M. High school students' perceptions of how major global environmental effects might cause skin cancer. *J. Environ. Educ.* **29,** 31–36 (1998).
34. Boyes, E., Stanisstreet, M. & Papantoniou, V. S. The ideas of Greek high school students about the ozone layer. *Sci. Educ.* **83,** 724–737 (1999).
35. Tsurusaki, B. K. & Anderson, C. W. Students' understanding of connections between human engineered and natural environmental systems. *Int. J. Environ. Sci. Educ.* **5,** 407–433 (2010).
36. Donner, S. D. & McDaniels, J. The influence of national temperature on opinions about climate change in the US since 1990. *Climatic Change* **118,** 537–550 (2013).
37. Nisbet, M. C. & Mooney, C. Framing science. *Science* **316,** 56 (2007).
38. Boykoff, M. T. Flogging a dead norm? Newspaper coverage of anthropogenic climate change in the United States and United Kingdom from 2003–2006 *Area* **39,** 470–481 (2007).
39. Verhey, S. D. The effect of engaging prior learning on student attitudes toward creationism and evolution. *BioScience* **55,** 996–1003 (2005).
40. Scott, E. C. & Branch, G. Evolution: What's wrong with 'teaching the controversy'. *Trends Ecol. Evol.* **18,** 499–502 (2003).
41. Walsh, E. M. *An Examination of Climate Scientists' Participation in Education: Implications for the Teaching and Learning of Socially Controversial Science* (Univ. Washington, College of Education, 2012).
42. Roehrig, G. *et al.* in *Ann. Meet. Assoc. Sci. Teach. Educ.* (Clear Water Beach, Florida, 2012); http://go.nature.com/JURSTP
43. National Research Council *Climate Change Education: Goals, Audiences and Strategies. A Workshop Summary* (rapporteurs Forrest, S. & Feder, M. A.) (The National Academies Press, 2011).
44. Alexander, C. *et al.* Linking indigenous and scientific knowledge of climate change. *Bioscience* **61,** 477–484 (2011).
45. IPCC *Climate Change 2007: Impacts, Adaptation and Vulnerability* (eds Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. & Hanson, C. E.) (Cambridge Univ. Press, 2007).

46. Wibeck, V. Enhancing learning, communication and public engagement about climate change — some lessons from recent literature. *Environ. Educ. Res.* http://dx.doi.org/10.1080/13504622.2013.812720 (2013).
47. Clayton S. *et al.* Connecting to nature at the zoo: implications for responding to climate change. *Environ. Educ. Res.* http://dx.doi.org/10.1080/13504622.2013.816267 (2013).
48. Sadler, T. D. Informal reasoning regarding socioscientific issues: a critical review of research. *J. Res. Sci. Teach.* **41,** 513–536 (2004).
49. Rose, S. L. & Calabrese Barton, A. Should great lakes city build a new power plant? How youth navigate socioscientific issues. *J. Res. Sci. Teach.* **49,** 541–567 (2012).
50. Kahan, D. M. *et al.* The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Clim. Change.* **2,** 732–735 (2012).
51. McCaffrey, M. & Rosenau, J. Science literacy still matters. *Nature Clim. Change.* **2,** 636 (2012).
52. Rockoff, J. E. The impact of individual teachers on student achievement: evidence from panel data. *Am. Econ. Rev*. **94,** 247–252 (2004).
53. Bell, P. in *Internet Environments for Science Education* (eds Linn, M., Davis, E. & Bell, P.) 233–260 (Lawrence Erlbaum Associates, 2004).

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