Integrating the social sciences to enhance climate literacy

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The climate literacy movement aspires to help members of the general public understand the global climate system, locate and assess scientifically credible climatic information, communicate about climate change in an educated and objective manner, and make informed and responsible decisions in response to climate-change impacts. When these goals are not met, society will likely be further imperiled by the effects of a changing climate. Climate literacy programs have traditionally promoted education on the biophysical science of the climate system but have largely failed to integrate relevant knowledge from the social sciences. We argue that understanding human behavior and the social drivers of climate change are essential for the public to fully appreciate the climate system, and that this knowledge can inform decision making related to climate-change mitigation and adaptation. Teaching students to evaluate different forms of evidence will also improve climate literacy and lead them to ask how scientists know what they know. Finally, we suggest two new social science principles that could advance interdisciplinary climate literacy goals.

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To achieve climate literacy, individuals must (1) understand the basic principles of Earth's climate system, (2) be able to assess scientifically credible information about the climate, (3) meaningfully communicate about climate and climate change, and (4) make informed and responsible decisions about climate change (USGCRP 2009). It is imperative that political leaders, decision makers, and the general public possess these skills to better ensure that they adopt effective climate-change mitigation and adaptation strategies that depart from the status quo and decrease the probability of costly future biophysical and social impacts such as sea-level rise, drought, migration, and territorial conflicts (Kopp *et al.* 2016). Coordinated efforts to improve climate literacy have been underway for over two decades, culminating in 2009 with the National Oceanic and Atmospheric Administration's (NOAA's) publication entitled Climate Literacy: The Essential Principles of Climate Sciences (USGCRP 2009; Panel 1). Developed in collaboration with several US government and science agencies, non-governmental organizations, and individual scientists and educators, this guide offers a consensus on what climate literacy is and why it is important. The guide has been used extensively in educational efforts to improve climate literacy.

We believe that achieving these climate literacy goals will require an interdisciplinary approach that more fully integrates social science knowledge with biophysical science knowledge. The argument for assimilating the social sciences within climate literacy is twofold. The first rationale is that increased knowledge about social, political, and economic systems and their interconnectedness with climate phenomena will enable a more sophisticated climate literacy. Clearly, incorrect mental models about the climate system (eg conflating climate and weather, or confusing stratospheric ozone depletion with climate change) are barriers to achieving climate literacy (Sterman and Sweeney 2007; Reynolds *et al.* 2010). But faulty models about social, political, and economic systems are just as damaging to climate literacy, given that they can foster misunderstanding about how those systems contribute to climate change as well as possibilities for mitigation and adaptation. Thus, advocating for improved knowledge of social, political, and economic systems will contribute to greater climate literacy. While little is known about people's mental models of the human dimensions of climate change, preliminary research suggests that social beliefs influence climate-change engagement. For example,

In a nutshell:

- It is just as important for members of the general public to understand the interactions between human behavior and climate change as it is for them to understand the climate system itself
- Disciplines within the social sciences can improve society's ability to assess scientifically credible information about the climate, to communicate ideas about climate change, and to make informed and responsible decisions about mitigation and adaptation
- The social sciences must be more fully integrated into current climate literacy principles and efforts in order to achieve a more interdisciplinary and effective climate literacy

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Panel 1. The seven principles of climate science literacy (USGCRP 2009)

Developed by climate scientists and educators, these principles were meant to identify the knowledge that people need to reach climate literacy goals. We provide additional social science insights on principles 3, 5, 6, and 7 (italicized for emphasis).

(1) The Sun is the primary source of energy for Earth's climate system.
(2) Climate is regulated by complex interactions among components of the Earth system.
(3) *Life on Earth depends on, is shaped by, and affects climate.*
(4) Climate varies over space and time through both natural and human-made processes.
(5) *Our understanding of the climate system is improved through observations, theoretical studies, and modeling.*
(6) *Human activities are impacting the climate system.*
(7) *Climate change will have consequences for the Earth system and human lives.*

beliefs about the effectiveness of individual and collective action influence decisions to work toward mitigating climate change and participate in political actions (Lorenzoni *et al.* 2007; Roser-Renouf *et al.* 2014).

The second rationale is that scientific literacy may be strengthened through an improved understanding of practices in both the social sciences and biophysical sciences (Figure 1). In formal and informal educational settings, teaching the social and biophysical sciences provides more opportunities for students to learn how rigorous theory, data collection, and analysis across multiple disciplines may be used to address real-world problems with wide-ranging societal implications. The key here is teaching not only what social and biophysical scientists know about climate change, but also how these scientists know what they know. Understanding the methodological and analytical similarities and differences across climate-change-relevant disciplines can further enhance climate literacy (McCright *et al.* 2013).

Social scientists have amassed substantial bodies of knowledge relevant to climate change (Figure 2). The American Association of Geographers has had an interdisciplinary working group on geography and climate change since 2010 and has featured climate change as a main theme of their conferences in 2010 (Aspinall 2010) and 2014. In addition, several other social science disciplines, including psychology (Swim *et al.* 2009), anthropology (Fiske *et al.* 2014), and sociology (Dunlap and Brulle 2015), have recently summarized the state of their respective disciplinary knowledge about climate change. These reports suggest that social scientists are prepared to promote climate literacy.

This paper echoes previous calls for greater participation by social scientists in climate science and climate education (Victor 2015). To facilitate such integration, we identify social science knowledge that is vital for cultivating climate literacy. One goal of this paper is to enable those developing and teaching climate curricula in various educational settings to begin to incorporate social science knowledge and practices into those efforts. Although economics is unquestionably a relevant social science, we do not include it directly in this review because it is already the most cohesive and influential social science, receiving consistent attention from bodies such as the Intergovernmental Panel on Climate Change (IPCC) (Brewer and Stern 2005; Victor 2015).

Here, we offer a framework for integrating social science knowledge into climate literacy. We first identify and discuss the most robust social science knowledge relevant to four of the seven climate literacy principles established in the previously mentioned NOAA report (USGCRP 2009; Panel 1). We then propose two additional principles (Table 1) that would advance the climate literacy goals of helping the public assess climate-change information, communicate effectively, and make educated decisions about climate change. Finally, we identify next steps to make climate literacy more interdisciplinary.

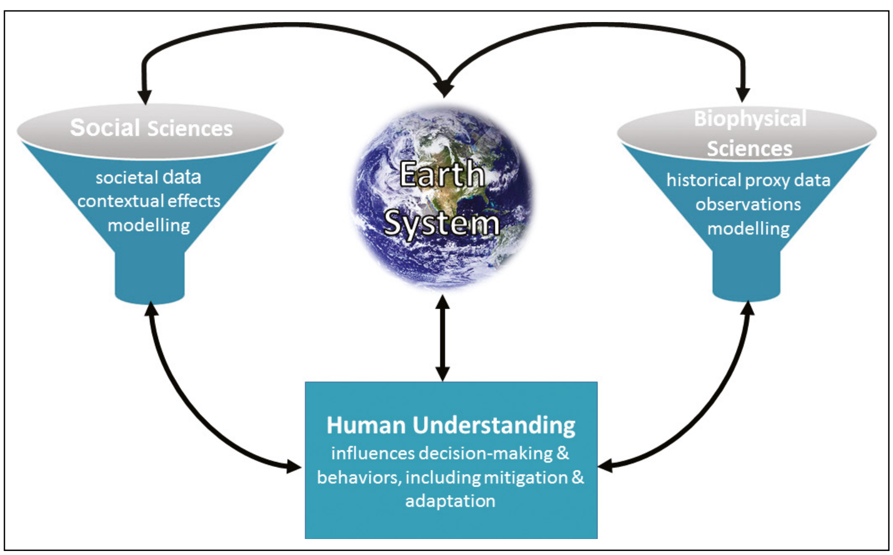

Figure 1. *Understanding the Earth system requires the social and biophysical sciences. Across disciplines, scientific practices use different kinds of data and methods to systematically build knowledge about the human–climate system. Integrating knowledge from across these disciplines enables responsible decision making and communication surrounding the problem of and responses to climate change.*

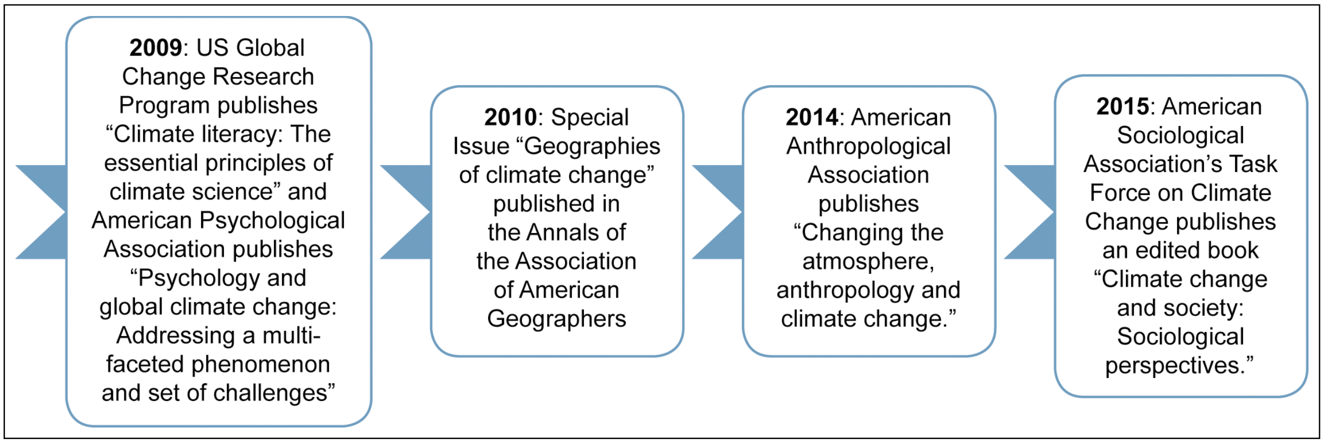

Figure 2. *Timeline of disciplinary contributions on climate change. The climate-oriented social sciences have made progress in knowledge accumulation after the initial publication of the climate science literacy principles in 2009.*

Four climate literacy principles

For four of the seven climate literacy principles (USGCRP 2009; Panel 1) that indicate the need for understanding human systems, we summarize the most relevant social science knowledge essential to achieve climate literacy. In each case we draw upon theoretically developed and empirically supported insights from the peer-reviewed literature, especially meta-analyses and syntheses that identify consensus.

Humans depend on and affect climate

The biophysical sciences have revealed the dynamic nature of the climate system. Current understanding of coupled human and natural systems as well as contemporary anthropogenic climate change can be enhanced with additional insights from archaeology and anthropology, demonstrating the impacts of climatic changes on and responses by human communities over time and across cultures (Figure 3).

Proxy data from ice cores, lake sediment, and pollen remains have been analyzed alongside the archaeological record to provide clues about human evolutionary history. While it is difficult to prove direct links between climatic shifts and various stages in hominid evolution, the co-occurrence of these events over time, notably between four and six million years ago and during glacial onset around two million years ago, strongly suggests that climate played a major role in the evolution of early hominids (deMenocal 1995).

Climatic variables have also been implicated in the development of agriculture and complex societies. The rise of agriculture can be linked to an extensive period of climate fluctuation, when a longer-term warming trend was abruptly interrupted by a sudden "big freeze" of 1300 years and a prolonged dry period (Fagan 2004). Scholars hypothesize that these dry conditions drove human populations to migrate toward water sources, adopt more sedentary lifestyles, and increase their experimentation with the harvesting and the domestication of plants. Indeed, many archaeological studies reveal that major shifts in population and settlement coincide with changes in precipitation, temperature, sea level, and vegetation (Fagan 2004; Anderson *et al.* 2011). Several long-term droughts, lasting for decades or even centuries in the archeological record, appear to have had dire consequences for humans, including abandonment of urban settlements and the collapse of entire states (Kennett *et al.* 2012; Barnes *et al.* 2013).

There are also many examples – across a range of time periods and geographical regions – of societies that have adapted to highly inhospitable and variable environments (Ellis 2011; Scarborough *et al.* 2012). A long-term perspective on the relationship between climate and human societies reveals a nuanced picture illustrating that changes in the climate have evoked both highly successful and disastrous human responses (Crumley 2002; Costanza *et al.* 2007).

Table 1. Newly proposed social science principles and their rationale

Proposed social science principle	*Rationale for how it advances climate literacy*
Public understanding of climate change is a social and psychological phenomenon	-Knowledge of what influences perceptions of climate change can help citizens better assess claims about climate change that they hear and help them discuss climate change with others
Social contexts can enhance or constrain mitigation and adaptation	-Provides citizens with an appreciation of the benefits of collective action and policy changes -Provides civic literacy for citizens on how to engage in collective action

Figure 3. *This picture of children playing near an ice-encrusted river illustrates how daily activities depend upon the local climate. The role of climate in influencing human activities and evolution has often been taken for granted, yet humans continue to alter the climate.*

Furthermore, there is evidence that human activities have influenced the climate for much longer than is commonly understood. While the scale and pace of human impacts has markedly accelerated over the past half century, one impact – intentionally clearing forests for agriculture and fuelwood – dates back to nearly 6000 years ago. This process reduces the forests' ability to return moisture to the atmosphere via evapotranspiration, resulting in less rainfall and altering the climate on a regional scale. During approximately the same time period, there is evidence that humans cultivated rice using controlled irrigation, a process that led to a 100 parts per billion increase in atmospheric methane (CH_4) between 5000 and 3000 years ago (Ruddiman 2005).

Human activities are impacting the climate

Social science work in recent decades has improved our understanding of how anthropogenic climate-change drivers in the modern industrial era affect the climate across multiple temporal and geographical scales. Empirical studies focus on various levels of organization (global, regional, nation-state, industry, community, and household) where each level of organization is connected to the others. These studies reveal that different nations, industries, organizations, and households are unequal contributors to climate change, with some doing far more damage than others (Druckman and Jackson 2009; Jorgenson *et al*. 2016).

Analyses of the human drivers of atmospheric greenhouse-gas (GHG) emissions consistently demonstrate that nations' population size and gross domestic product per capita are direct predictors of GHG emissions (Rosa and Dietz 2012). The emissions associated with a small increase in population in a country with high levels of consumption are roughly equivalent to the emissions associated with a large increase in population in a country with low levels of consumption. Population growth has been reduced indirectly by increasing resources and opportunities (both economic and educational) for women, increasing access to contraception, and improving maternal and child health (Bryant 2007).

Direct home energy use, transportation energy use, and food consumption – particularly meat and foods produced by industrial agriculture – are the top three categories of GHG-intensive consumption among households (Shwom and Lorenzen 2012). GHG-intensive patterns of consumption are highly influenced by levels of economic development and also, to a more variable extent, by cultural factors such as institutions, values, beliefs, and norms. For example, California has development equal to that of other US states but uses 43% less electricity per household than the rest of the US due to different economic and institutional policies (Kandel *et al*. 2008).

Research on the anthropogenic drivers of land-use and land-cover change reveals how and why humans influence the climate through altering the Earth's reflectivity, affecting the Earth's ability to take up carbon, and releasing carbon that was previously stored to the atmosphere. Deforestation is an emissions source and decreases the size of terrestrial carbon sinks. The main source of household consumption contributing to deforestation is the demand for wooden furniture, for food products made with palm oil, and for beef and dairy products. The institutional drivers of deforestation and reforestation vary over space and time and include cattle-raising complexes in Latin America and logging-related deforestation in Southeast Asia (Rudel 2013). Understanding the complexities and spatiotemporal variation of emissions production can help members of the public become more informed about mitigation and adaptation strategies and thus become more climate literate.

Climate-change effects on Earth systems and human lives

Current GHG concentrations and emissions are already leading to predicted climate impacts. Increasing GHGs will lead to more dramatic changes that may affect human settlement patterns, the built environment, provision of ecosystem services (including food production and access to clean water), and human health, as well as lead to armed conflict between groups. The extent and distribution of these societal consequences are influenced not only by climate but also by human and biophysical factors. The social sciences have helped to define concepts – such as risk, adaptive capacity, vulnerability, and resilience – that integrate these factors and that aid in the development of assessment tools, analysis of system-wide effects, and the creation of design solutions (Nelson 2011; IPCC 2014).

Direct engagement with local communities and examination of the historical and cross-cultural record of human–environment interactions have also shown that environmental risk perceptions, depth of climate knowledge, societal values, and acceptance of climate adaptation measures are highly context-dependent (Füssel and Klein 2006; Nelson 2011; Adger *et al.* 2013). There is no simple causal relationship between environmental risks and social responses; rather, scientists observe variable responses that are strongly influenced by culture and geography (Costanza *et al.* 2007; Adger *et al.* 2013).

Climate risk is a function of exposure to both physical hazards and vulnerability to societal conditions such as high levels of poverty and inequality and a lack of political power, social capital, and access to resources (Fiske *et al.* 2014). Some societies are much more vulnerable to these circumstances than others, and levels of adaptive capacity are not equally distributed globally (Barnes *et al.* 2013). Migration, for example, is often necessary when climatic conditions make some locations uninhabitable, but the option is typically more readily available to those with adequate economic resources (Black *et al.* 2011). When low-income migrants are able to move, they often end up on low-cost marginal lands that are equally prone to natural hazards (Adger *et al.* 2013). To date, those most vulnerable to climate-change impacts have often been the least responsible for GHG emissions. Furthermore, the adaptive efforts of wealthier societies have, in some cases, worked to perpetuate inequality and generate negative impacts for other societies, or the system as a whole (Adger *et al.* 2011; Isenhour and Feng 2016).

Despite variability in climate-related stress and adaptive response, several general patterns emerge from historical and contemporary cross-cultural comparisons. Briefly, adaptation is more likely to be successful when subsistence systems are highly diversified, when societies focus on innovation rather than conformity, and when governance systems are responsive and flexible (Van der Leeuw 2008; Fiske *et al.* 2014). However, the pace and scale of climate change today is unprecedented in human history, and various contemporary socio-political factors increase vulnerability – including, for example, high population densities, urbanization, static geopolitical borders that limit the ability to migrate, and inflexible systems of governance.

Observations, theoretical studies, and modeling

Examining the emergence, trajectory, and current state of climate science allows for a more historical perspective and nuanced understanding of climate change. The modern era of climate science began in the post-World War II (WWII) period when carbon-cycle researchers and atmospheric modelers first began to collaborate (Hart and Victor 1993). Climate science grew during this post-WWII era of "big science" with the help of large federal and international investments in climate monitoring stations, integrated computer networks, and satellite-based sensors. At the same time, supercomputer capabilities continued to expand, complex modeling systems grew more proficient, and, with the advent of extensive integrated scientific assessments, the sciences became an increasingly globalized endeavor (Edwards 2010).

Climate science faces major challenges associated with facilitating collaboration among thousands of scientists across many disciplines. These scientists have different accepted rules about what counts as empirical evidence and how it should be interpreted. They also have different preferred analytical techniques and various ways of producing knowledge. Research in this area tends to focus on: (1) how climate scientists depict and communicate uncertainty (not only to facilitate collaboration across disciplines but also to engage with policy makers and citizens) (Zehr 2000; Budescu *et al.* 2009) and (2) how scientists create and test climate models using historical and contemporary observational data (Lahsen 2005; Lloyd 2012).

Research provides insights into how scientific knowledge accumulates via development of theory, empirical studies, and the peer-review process. Given the public's skepticism of climate science and non-experts' difficulty with interpreting uncertainty, it may be useful to develop curricula devoted to the study of science in order to enrich public understanding of how climate science actually works. For example, social scientists note that many scientific estimates in integrated climate science assessments (eg IPCC reports) are inherently conservative (Brysse *et al.* 2013). Also, much is known about the nature and extent of the scientific consensus on anthropogenic climate change. For instance, studies debunk the popular trope that there was scientific agreement in the 1970s on "global cooling" (Peterson *et al.* 2008). Studies analyzing the peer-reviewed scientific literature and surveys of climate scientists independently confirm that there is scientific consensus that anthropogenic climate change is occurring (Cook *et al.* 2016), and the social science literature has found that belief in this scientific consensus is correlated with climate-change policy support and actions (Ding *et al.* 2011).

Two new climate literacy principles

Several established social science fields have created robust knowledge that is relevant to climate literacy but that does not align well with the existing climate literacy principles in the NOAA report (USGCRP 2009). This research goes beyond climate models and basic mechanics of the greenhouse effect and provides insights into the human dimensions of climate change as a social problem. Here, we propose two new climate-related social science principles that, we argue, are likely to improve citizens' ability to assess climate science information, communicate effectively about the changing climate, and make informed and responsible decisions about climate change (Table 1).

A social and psychological phenomenon

When people recognize why they perceive climate change in a particular way, they can better assess new scientific information and communicate with others about climate change. Since the late 1990s, over 100 peer-reviewed studies have examined predictors of public understanding of climate change through analyses of nationally representative survey data. While some of these studies analyzed data from countries around the world, most work focused on the US. The strongest and most consistent predictors of climate-change views are environmental values, identity, political orientation (both political ideology and party identification), and gender (McCright *et al.* 2016). Individuals espousing pro-environmental values or identities, liberals/Democrats, and females are more accepting of the scientific consensus on climate change than are each of their respective counterparts. Public understanding of climate change is also important because accurate knowledge of the causes of climate change has been found to predict climate-friendly behaviors (Bord *et al.* 2000).

Public understanding of climate change also varies considerably cross-nationally, even as it has generally improved over time due in large part to increasing media coverage (Shwom *et al.* 2015). An estimated 7–15% of US citizens are skeptical of climate science and deny the reality and seriousness of climate change; these proportions are relatively high as compared to the proportions of like-minded citizens in other nations (Dunlap and McCright 2015). In general, however, societies around the world perceive the impacts of climate change to be less severe and as a more distant possibility than the immediate impacts of other environmental problems (Brechin and Bhandari 2011).

Social contexts can enhance or constrain mitigation and adaptation

Despite aiming to enable individuals to make responsible decisions, current climate literacy principles provide little guidance on what options are available to mitigate or adapt to climate change. Individuals, groups, and governments can take mitigative and adaptive actions that vary in scope and means of implementation (Adger *et al.* 2005). Households and communities have made efforts to enhance their adaptive capacity, ranging from infrastructural improvements to migration. For example, in Bangladesh's northern territories, approaches are under development to grow food in increasingly flooded areas using technologies like floating gardens (Ayers and Forsyth 2009). However, factors such as cost or existing technological infrastructure can limit the effectiveness of these efforts. For example, unless a household can afford to go off-grid completely, it is tied to the choices that electric utility companies make for fuel input, and those are influenced by markets and policies. When citizens understand this dilemma, they can appreciate the benefits of collective action and policy changes; this highlights the importance of civic literacy for guiding action.

Some citizens believe that the government is uninterested in or ineffective at addressing climate change and are therefore not inclined to engage politically or invest time or money to support policies (Lorenzoni *et al.* 2007). Although effective national and international policies have been difficult to enact, cities, states, regions, and the US as a whole have actually adopted extensive climate change mitigation and adaptation plans. For example, it is unlikely that, during the current presidential administration, the US will regulate coal plant GHG emissions at a national level via the federal Clean Air Act, but many climate-change policies (eg carbon taxes, carbon cap and trade, or renewable portfolio standards for utilities) are being implemented at the state and local levels (Rabe 2004). In fact, in 2008, approximately 45% of the US population lived in states where there were GHG reduction targets (Lutsey and Sperling 2008) and this number is likely higher in 2017. Citizens should know that if they wish to voice opinions about or influence climate policies, they can engage with multiple levels of governance by contacting their federal, state, and local representatives.

As discussed above, the costs and benefits of continuing business as usual or responding will be taken on by different groups. Citizens must understand that political systems will determine the process through which the costs and benefits of climate change will be distributed. Current and future generations most impacted by climate change are different stakeholders than those who will be affected by mitigation policies. Most efforts to deny climate science findings and undermine practices that provide input into climate-change policy have been driven by powerful economic and ideological groups defending the industrial capitalist system and opposing market regulations (Kolk and Pinkse 2007; Dunlap and McCright 2015).

Advancing interdisciplinary climate literacy: future directions

To advance climate literacy, similar to how the US Global Change Research Program (USGCRP) developed its seven existing principles, we argue that the framework outlined above should be shared with a diversity of climate-oriented professionals, comprising social scientists (including but not limited to economists), educators, and those within the humanities. Indeed, climate literacy could foster innovative and insightful thinking, one of the overarching goals of the humanities (American Academy of Arts and Sciences 2013). Both the humanistic reaches of the social sciences, such as sociocultural anthropology and the sociology of culture, as well as the traditional humanities that study values, beliefs, language, culture, history, and meaning, assist with interpreting society's relationships with nature and the decisions required to shape society and the environment in the future. For example, the humanities might explain how stories about climate change help to make sense of the changing world (Hulme 2011). Similarly, ethical reasoning can enable the public to identify and grapple with the challenging issues of climate change, such as how society's actions reflect fairness, responsibility, and other values (Gardiner and Hartzell-Nichols 2012). These capabilities enhance climate literacy by helping citizens make climate-related decisions that account for human diversity and trade-offs in social, economic, and environmental spheres (American Academy of Arts and Sciences 2013).

This process also could be used to establish a broad and robust research agenda to demonstrate the humanistic and social science dimensions of climate literacy. Such an agenda could determine what information would be beneficial for reaching literacy goals, which aspects of social science would be useful for the public to know but are currently underdeveloped or understudied, and which mental models people hold about how social, political, and economic systems cause and react to climate change. Just as research into science education has helped to develop targeted efforts to promote climate literacy, research is needed to better determine how the public understands the social world.

Once the above process is well underway and we have identified which human dimensions of climate change should be integrated into a broader climate literacy, the question then becomes how we can include the social sciences in climate literacy education. This would involve helping educators develop more interdisciplinary instructional materials as well as helping students learn across the social and biophysical sciences. This challenge can be answered only by bringing together leading climate literacy practitioners, those who study education in the biophysical and social sciences, and climate scientists from those disciplines.

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References

Adger WN, Arnell NW, and Tompkins EL. 2005. Successful adaptation to climate change across scales. *Global Environ Chang* **15**: 77–86.

Adger WN, Barnett J, Brown K, *et al.* 2013. Cultural dimensions of climate change impacts and adaptation. *Nat Clim Change* **3**: 112–17.

Adger WN, Brown K, Nelson DR, *et al.* 2011. Resilience implications of policy responses to climate change. *WIREs Clim Change* **2**: 757–66.

American Academy of Arts and Sciences. 2013. The heart of the matter: humanities and social sciences for a vibrant, competitive and secure nation. Cambridge, MA: American Academy of Arts and Sciences.

Anderson DG, Maasch K, and Sandweiss DH (Eds). 2011. Climate change and cultural dynamics: a global perspective on mid-Holocene transitions. Amsterdam, The Netherlands; Boston. MA: Elsevier/Academic Press.

Aspinall R. 2010. Geographical perspectives on climate change. *Ann Assoc Am Geogr* **100**: 715–18.

Ayers J and Forsyth T. 2009. Community-based adaptation to climate change. *Environment* **51**: 22–31.

Barnes J, Dove M, Lahsen M, *et al.* 2013. Contribution of anthropology to the study of climate change. *Nat Clim Change* **3**: 541–44.

Black R, Adger WN, Arnell NW, *et al.* 2011. The effect of environmental change on human migration. *Global Environ Chang* **21**: S3–S11.

Bord RJ, O'Connor RE, and Fisher A. 2000. In what sense does the public need to understand global climate change? *Public Underst Sci* **9**: 205–18.

Brechin SR and Bhandari M. 2011. Perceptions of climate change worldwide. *WIREs Clim Change* **2**: 871–85.

Brewer GD and Stern PC. 2005. Introduction. In: Brewer GD and Stern PC (Eds). Decision making for the environment: social and behavioral science research priorities. Washington, DC: National Academies Press.

Bryant J. 2007. Theories of fertility decline and the evidence from development indicators. *Popul Dev Rev* **33**: 101–27.

Brysse K, Oreskes N, O'Reilly J, *et al.* 2013. Climate change prediction: erring on the side of least drama? *Global Environ Chang* **23**: 327–37.

Budescu DV, Broomell S, and Por H-H. 2009. Improving communication of uncertainty in the reports of the Intergovernmental Panel on Climate Change. *Psychol Sci* **20**: 299–308.

Cook J, Oreskes N, Doran PT, *et al.* 2016. Consensus on consensus: a synthesis of consensus estimates on human-caused global warming. *Environ Res Lett* **11**: 048002.

Costanza R, Graumlich L, Steffen W, *et al.* 2007. Sustainability or collapse: what can we learn from integrating the history of humans and the rest of nature? *Ambio* **36**: 522–27.

Crumley CL. 2002. New directions in anthropology and environment: intersections. Latham, MD: Altamira Press.

deMenocal PB. 1995. Plio-Pleistocene African climate. *Science* **270**: 53–59.

Ding D, Maibach EW, Zhao X, *et al.* 2011. Support for climate policy and societal action are linked to perceptions about scientific agreement. *Nat Clim Change* **1**: 462–66.

Druckman A and Jackson T. 2009. The carbon footprint of UK households 1990–2004: a socio-economically disaggregated, quasi-multi-regional input–output model. *Ecol Econ* **68**: 2066–77.

Dunlap RE and Brulle RJ (Eds). 2015. Climate change and society: sociological perspectives. Cambridge, UK: Oxford University Press.

Dunlap RE and McCright AM. 2015. Challenging climate change. In: Dunlap RE and Brulle RJ (Eds). Climate change and society: sociological perspectives. Cambridge, UK: Oxford University Press.

Edwards PN. 2010. A vast machine: computer models, climate data, and the politics of global warming. Cambridge, MA: MIT Press.

Ellis EC. 2011. Anthropogenic transformation of the terrestrial biosphere. *Philos T Roy Soc A* **369**: 1010–35.

Fagan B. 2004. The long summer: how climate changed civilization. New York, NY: Basic Books.

Fiske SJ, Crate SA, Crumley CL, *et al*. 2014. Changing the atmosphere – anthropology and climate change. Final report of the AAA Global Climate Change Task Force. Arlington, VA: American Anthropological Association.

Füssel H-M and Klein RJ. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change* **75**: 301–29.

Gardiner S and Hartzell-Nichols L. 2012. Ethics and global climate change. *Nature Education Knowledge* **3**: 5.

Hart DM and Victor DG. 1993. Scientific elites and the making of US policy for climate change research, 1957–74. *Soc Stud Sci* **23**: 643–80.

Hulme M. 2011. Meet the humanities. *Nat Clim Change* **1**: 177–79.

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate change 2014 – impacts, adaptation and vulnerability: regional aspects. Cambridge, UK: Cambridge University Press.

Isenhour C and Feng K. 2016. Decoupling and displaced emissions: on Swedish consumers, Chinese producers and policy to address the climate impact of consumption. *J Clean Prod* **134**: 320–29.

Jorgenson A, Longhofer W, and Grant D. 2016. Disproportionality in power plants' carbon emissions: a cross-national study. *Sci Rep* **6**: 28661.

Kandel A, Sheridan M, and McAuliffe P. 2008. A comparison of per capita electricity consumption in the United States and California. Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings: 8.123-34. Washington, DC: American Council for an Energy Efficient Economy.

Kennett DJ, Breitenbach SF, Aquino VV, *et al*. 2012. Development and disintegration of Maya political systems in response to climate change. *Science* **338**: 788–91.

Kolk A and Pinkse J. 2007. Multinationals' political activities on climate change. *Bus Soc* **46**: 201–28.

Kopp RE, Shwom R, Wagner G, *et al*. 2016. Tipping elements and climate–economic shocks: pathways toward integrated assessment. *Earth's Future* **4**: 346–72.

Lahsen M. 2005. Seductive simulations? Uncertainty distribution around climate models. *Soc Stud Sci* **35**: 895–922.

Lloyd EA. 2012. The role of 'complex' empiricism in the debates about satellite data and climate models. *Stud Hist Philos Sci* **43**: 390–401.

Lorenzoni I, Nicholson-Cole S, and Whitmarsh L. 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environ Chang* **17**: 445–59.

Lutsey N and Sperling D. 2008. America's bottom-up climate change mitigation policy. *Energ Policy* **36**: 673–85.

McCright AM, Marquart-Pyatt ST, Shwom RL, and Brechin S. 2016. Ideology, capitalism, and climate: explaining public views about climate change in the United States. *Energy Res Soc Sci* **21**: 180–89.

McCright AM, O'Shea BW, Sweeder RD, *et al*. 2013. Promoting interdisciplinarity through climate change education. *Nat Clim Change* **3**: 713–16.

Nelson DR. 2011. Adaptation and resilience: responding to a changing climate. *WIREs Clim Change* **2**: 113–20.

Peterson TC, Connolley WM, and Fleck J. 2008. The myth of the 1970s global cooling scientific consensus. *B Am Meteorol Soc* **89**: 1325.

Rabe BG. 2004. Statehouse and greenhouse: the emerging politics of American climate change policy. Washington, DC: Brookings Institution Press.

Reynolds TW, Bostrom A, Read D, *et al*. 2010. Now what do people know about global climate change? Survey studies of educated laypeople. *Risk Anal* **30**: 1520–38.

Rosa EA and Dietz T. 2012. Human drivers of national greenhouse-gas emissions. *Nat Clim Change* **2**: 581–86.

Roser-Renouf C, Maibach EW, Leiserowitz A, *et al*. 2014. The genesis of climate change activism: from key beliefs to political action. *Climatic Change* **125**: 163–78.

Ruddiman W. 2005. How did humans first alter global climate? *Sci Am* **292**: 46–53.

Rudel TK. 2013. Tropical forests: paths of destruction and regeneration. New York, NY: Columbia University Press.

Scarborough VL, Dunning NP, Tankersley KB, *et al*. 2012. Water and sustainable land use at the ancient tropical city of Tikal, Guatemala. *P Natl Acad Sci USA* **109**: 12408–13.

Shwom R and Lorenzen JA. 2012. Changing household consumption to address climate change: social scientific insights and challenges. *WIREs Clim Change* **3**: 379–95.

Shwom RL, McCright AM, Brechin SR, *et al*. 2015. Public opinion on climate change. In: Dunlap RE and Brulle RJ (Eds). Climate change and society: sociological perspectives. Cambridge, UK: Oxford University Press.

Sterman JD and Sweeney LB. 2007. Understanding public complacency about climate change: adults' mental models of climate change violate conservation of matter. *Climatic Change* **80**: 213–38.

Swim J, Clayton S, Doherty T, *et al*. 2009. Psychology and global climate change: addressing a multi-faceted phenomenon and set of challenges. www.apa.org/releases/climate-change.pdf. Viewed 16 Jun 2017.

USGCRP (US Global Change Research Program). 2009. Climate literacy: the essential principles of climate science. Washington, DC: NOAA Climate Program Office.

Van der Leeuw SE. 2008. Climate and society: lessons from the past 10,000 years. *Ambio* **37**: 476–82.

Victor DG. 2015. Embed the social sciences in climate policy. *Nature* **520**: 27–29.

Zehr SC. 2000. Public representations of scientific uncertainty about global climate change. *Public Underst Sci* **9**: 85–103.

