Title
The building of knowledge, language, and decision-making about climate change science: a cross-national program for secondary students

Journal
International Journal of Science Education, 38(6)

ISSN
0950-0693

Authors
Arya, Diana
Maul, Andrew

Publication Date
2016-04-12

DOI
10.1080/09500693.2016.1170227

International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

The building of knowledge, language, and decision-making about climate change science: a cross-national program for secondary students

Diana Arya & Andrew Maul

To cite this article: Diana Arya & Andrew Maul (2016): The building of knowledge, language, and decision-making about climate change science: a cross-national program for secondary students, International Journal of Science Education, DOI: 10.1080/09500693.2016.1170227

To link to this article: http://dx.doi.org/10.1080/09500693.2016.1170227

Published online: 03 May 2016.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2016
http://dx.doi.org/10.1080/09500693.2016.1170227

The building of knowledge, language, and decision-making about climate change science: a cross-national program for secondary students

Diana Arya and Andrew Maul

Gevirtz Graduate School of Education, University of California, Santa Barbara, CA, USA

ABSTRACT
The United Nations' declaration on climate change education in December 2014 has sparked a renewal of policies and programs initiated during the 'Decade of Education for Sustainable Development' (DESD, 2005–2014), aimed at promoting awareness, understanding, and civic action for environmental sustainability within learning communities all around the world. We present findings from a dialogic, multimodal, and literacies-based educational project designed to provide secondary students ($N = 141$) from four countries with the resources to read about and discuss evidence regarding climate change from seminal studies with peers and a core group of scientists ($N = 7$). Post-program interviews revealed a significant increase in language use related to evidence-based reasoning. Students also demonstrated an increased propensity to recycle. These findings support the hypothesis that providing opportunities for students to read and discuss seminal scientific sources incites positive changes in beliefs, attitudes, and behaviors related to climate change and climate science, and understandings of the nature of scientific evidence and argumentation.

ARTICLE HISTORY
Received 31 August 2015
Accepted 21 March 2016

KEYWORDS
Climate change science; evidence-based reasoning; academic language; new literacies

Introduction

In December 2014, ministers and heads of state gathered at the UN Climate Change Conference in Lima, Peru, and passed a declaration that aligns with previous efforts to elevate awareness and civic action for long-term environmental sustainability in learning communities all around the world (UNFCC, 2014). This declaration is a complementary extension of the 2005–2014 *Decade of Education for Sustainable Development* (DESD), as established by the United Nations Educational, Scientific and Cultural Organization (Buckler & Creech, 2014; Wals, 2012). The DESD framework is predicated on a view of learning as socially situated practices involving engagement in 'the complexities, controversies and inequities rising out of issues relevant to environment, natural heritage, culture, society and economy' (Wals, 2012, p. 12). This framework supports a model of learning that involves an open, critical dialogue in which students share and consider varying sources of knowledge and experience related to the Earth's changing climate

CONTACT Diana Arya darya@education.ucsb.edu Gevirtz Graduate School of Education, University of California, Santa Barbara, Santa Barbara, CA, USA

and subsequently develop a greater understanding about the unique process of science as a way of knowing about the natural world. Adolescent youth who attend secondary schools and programs are not often exposed to scientific discourse on issues of climate change that emphasizes the scientific process of evidence-based reasoning (Abd-El-Khalick et al., 2004; Bowker, 2005; Lemke, 1990), and thus often have little idea about the differences between scientific and social media sources. This blurry line between scientific sources and social media may confound students' (and teachers') abilities to reason and make informed views and decisions related to climate change.

Traditional models of science instruction as delivery of conceptual information are insufficient for fostering such critical, dialogic engagement with issues about an uncertain future. In their most recent report, UNESCO (Buckler & Creech, 2014) emphasized the importance of providing opportunities for students to actively consider the tensions between lifestyle consumption and green technologies and the subsequent complexities involved in consumptive decision-making. It is this notion of critical dialogue (i.e. engagement in problem solving with no clear solutions, or with multiple ideal solutions) and evidence-based reasoning that inspired the present study, which is a literacies-based (where 'literacies' refers to multimodal reading, discussions, and co-constructions about various sources of information related to climate change science) program for high school students in China, New Zealand, Norway, and the United States ($N = 141$). Over an eight-week period, participating students read and discussed a series of seminal studies related to climate change issues (e.g. rise in sea level) within their respective classroom sites and with the instructional guidance to consider, compare, and triangulate evidence presented in these studies and other relevant sources (e.g. Internet-based digital texts, personal experiences, journalistic sources) through discussions and co-constructions of summaries and Public Service Announcements (PSAs) that may in turn be shared with other students from across the participating sites through an online platform. Seven scientists from various disciplines engaged in these online discussions by serving the role of cultural guides (i.e. individuals with an insider's perspective, who help novices understand various cultural and linguistic practices; see Sanjek, 1993), offering clarifications and resources (if asked) and questions for spurring further considerations and discussion. This study is an investigation of changes in understanding, attitudes, and behaviors by the student participants over the course of this intervention. Specifically, we present findings from the initial iteration of an educational program, *Climate Exchange for Language and Learning* (CELL). Our explorative study is driven by two related research goals:

1. To explore the malleability of understandings, attitudes, and behaviors related to climate change science, the nature of science (NOS) as a way of knowing, and evidence-based reasoning through structured conversations (interviews).
2. To develop and refine a program that could be effective in shifting these understandings, attitudes, and behaviors.

Views and understandings about climate change continue to be shaped by political ideologies; in general, evidence suggests that political identity (i.e. one's inclination toward the ideologies of a particular group or party) has far greater influence on public perceptions of and attitudes toward climate change than the scientific evidence gathered about the Earth's changing climate (Hart, Feldman, Leiserowitz, & Maibach, 2015;

Unsworth & Fielding, 2014). Thus, political and cultural values remain a critical factor in influencing one's beliefs regarding global climate change (Hamilton, 2011; Whitemarsh, 2011).

What does it take to shift non-specialist perspectives on global climate change away from politically and ideologically influenced assumptions and toward evidence-based reasoning and explanations? This question inspired this study, the design of which was founded on the view of science and scientific knowledge building as rooted in literacy practices and processes; scientists engage in iterative bouts of reading, writing, and discussion as they investigate and disseminate (Bazerman, 1988; Latour & Woolgar, 1979). Further assuming the perspective of textual engagement as making sense of visual forms of communication (printed texts, graphics, video messages, etc.) within a sociocultural context (e.g. Gee, 2005; Jewitt, 2008; Lankshear & Knobel, 2011; Street, 2003), we investigated the changes in responses from pre- and post-program interviews about climate change issues and scientific processes. Specifically, we investigated changes in notions about the NOS as a way of knowing about the world, the complexities of climate change science, and what counts as scientific evidence, consumptive decision-making (via a waste removal task in the beginning of the individual interviews), and the use of academic and scientific language in the form of specific NOS-related concepts (*evidence*; *measures*) and scientific arguments supported by evidence-based reasoning (e.g. *humans are at least partly responsible for the increase in CO2 because we see from these studies that the levels of CO2 are higher than what would happen naturally*) in all pre- and post-program interview responses. Through the investigative frame of New Literacies Studies (NLS), we aimed to determine such changes in responses as a potential outcome of this intervention.

New literacies engagement in scientific texts

The NLS perspective is that in order for learning to happen, students must become active agents in their own exploration of multiple, multimodal sources of content both in and outside the classroom, including Internet searches and peer discussions that ultimately lead to co-constructions of knowledge for various purposes and audiences (Alvermann, 2002; Gee, 2005; Knobel, 2001). Notions of reading, writing, and discussion within this digital age present a varying, complex picture of meaning construction. The NLS framework was developed from the initiating work of the New London Group (2000; also see Kalantzis & Cope, 1997), an assembly of scholars who established a new definition of literacy that involved expanded notions of text (Internet websites, imagery, simulations, PSAs, etc.) and what counts as a literate language (e.g. leet speak). As such, the NLS perspective highlights the multimodal (linguistic, visual, audio, etc.) forms of meaning-making within an increasingly global community of active agents in the learning process, particularly within science (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 1990, 2001). The NLS perspective describes language in use as situated and 'connected' to the ways that people make sense of themselves and of the world (Freire & Macedo, 1987; Lemke, 1990; Pahl & Roswell, 2005). A shared emphasis in the new Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) is the engagement in diverse, contextualized media (CCSS, 2012; NGSS Lead States, 2013). This engagement also aligns with the Program for International Student Assessment

(PISA), which frames science literacy as the application of knowledge and skills in various real-life contexts (OECD, 2012). Further, many of the targeted competencies of the PISA 2015 framework for 'scientific literacy' such as explaining and interpreting data in multiple forms are examples of literacy practices within the NLS framework (Ares & Evans, 2014; Jewitt, 2008; Sørvik, Blikstad-Balas, & Ødegaard, 2015).

Scholars who study the social nature of engagement in digital literacies, particularly within science, posit that language in use is necessarily diverse in formality and register as members within a learning community pull from multiple sources of content, including previously learned content from school-based texts, personal experiences, and social media (Alvermann, 2002; Gee, 1991; Lankshear & Knobel, 2011; Lave & Wenger, 1991; Street, 1995). However, as scientific communities (including classroom communities) continue to work together to pose, evaluate, and revise conjectures (Latour & Woolgar, 1979), language use will shift toward greater precision and complexity in the use and explanation of scientific sources and concepts (Norris & Phillips, 2003; Norris, Phillips, & Osborne, 2007; Pearson, Moje, & Greenleaf, 2010; Snow, 2010).

Fostering a greater command of academic and scientific language. Many students struggle with the language demands of science classroom textbooks, lab assignments, exams, and instructional discourse, all of which are filled with unfamiliar and complex words and phrases, and in turn further compound the distance that already exists between the scientists and the student population (Bailey, 2007; Norris & Phillips, 2003; O'Brien, Stewart, & Moje, 1995; Snow, 2010). Further, many students come to the science classroom without the knowledge and experience about the language required to participate in discussions, reading activities, and collaborative tasks (Bailey, 2007; Norris & Phillips, 2003; Snow, 2010). Students need multiple exposures to less-frequently used vocabulary (i.e. academic vocabulary) in order to acquire word meanings from text (August, Carlo, Dressler, & Snow, 2005; Coxhead & Nation, 2001; Stahl, 2003). A linguistic analysis by Martin and Halliday (1993) revealed the highly technical semantic and syntactic elements in the communicative acts of a scientific community. The specialized language of science can be a difficult obstacle for those who are not at least moderately proficient in this language, thus inadvertently excluding the public from the work of scientists. This obstacle is further compounded with the challenge of navigating multiple, multimodal texts, and the varying contexts as previously described within the NLS framework. Adolescents are capable of reading and discussing challenging texts for purposes that closely align with scientific practices, yet are afforded little opportunity to engage in such dynamic literacies-based activities in the science classroom (e.g. Applebee, Langer, Nystrand, & Gamoran, 2003; Nystrand, Gamoran, Kachur, & Prendergast, 1997). This dynamic view of text engagement elevates the status of science from a collection of finalized, unchanging facts to a more complex, authentic exchange of ideas (Moje, Collazo, Carrillo, & Marx, 2001; Southerland, Smith, Sowell, & Kittleson, 2007).

It should be noted that our goal in this study was not to reduce the variability of language use in discussions related to NOS and climate change issues with an expectation for all program participants to only read, write, and speak with scientific and academic accuracy. Rather, as students are given the opportunity to pull from a variety of sources as they read, discuss, and write about their understanding about NOS-related processes and the Earth's changing climate, notions about what counts as scientific evidence are clarified through peer review in the form of open discussions that involve the facilitation of the participating scientists. Through these facilitated discussions, we hypothesize that students will develop knowledge, skills, and attitudes that more closely approximate the complex scientific practices and processes outlined by UNESCO's DESD framework (Buckler & Creech, 2014; Wals, 2012).

Related research

Encased within the NLS perspective are views of science learning as the social construction of knowledge that includes the scientific process of knowing about the natural world, and the differences between this specialized form of knowledge and other informational sources from political or social interest groups. We review each of these areas of research in turn.

Science learning through discussions about evidence. Learning has long been viewed as necessarily social; the importance of students exchanging ideas and co-constructing meaning for the development of linguistic and conceptual knowledge has been well documented in literacy research (Barton & Hamilton, 1998; Bazerman, 1982; Bomer & Bomer, 2001; Gee, 1996; Gutierrez, Baquedano-Lopez, & Tejaeda, 1999; Hicks, 1996; Lewis, 2001). Yet, often students spend the majority of a science class period responding to questions about facts from lectures and textbooks, leaving little time for such interactions (Ackerson & Abd-El-Khalick, 2005; Latour, 1987; Lederman, 1992). Traditional science classroom notions of the scientific method, for example, have been criticized for reflecting a myopic view of science; the contrived steps of inquiry oversimplify the complex and dynamic process of science and the conceptually oriented models that are employed by scientists across various fields (Abd-El-Khalick et al., 2004; Cartwright, 1983; Giere, 1988; Nersessian, 1999).

Developments in online, computer-mediated communication (CMC) have been recognized as valuable for facilitating conceptually deeper discussions that in turn lead to deeper understanding (Hoadley & Enyedy, 1999; Wertsch, 2002). However, school science curricula seldom include online interactions (Attewell, 2001; Debell & Chapman, 2003; Krueger, 2000; Reich, Murmane, & Willett, 2012). The CELL program was designed to incorporate CMC as a way to extend within-class discussions to exchanges beyond the classroom community by connecting online with students from the four research sites as well as with the consulting scientists.

Students' views of science. The abundance of research related to students' knowledge about science as a process of learning about the natural world has produced varied perspectives in how students' epistemic understanding should be characterized. Investigations by Lederman, Abd-El-Khalick, Ackerson, and other colleagues (e.g. Ackerson & Abd-El-Khalick, 2005; Ackerson, Abd-El-Khalick, & Lederman, 2000; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), for example, have focused on the NOS as a way of knowing as a tentative, empirical, theory-laden approach to studying the natural world; scientists actively use their imagination and creativity in their work, which is socially and culturally embedded (Lederman et al., 2002). These researchers have found that students and teachers across the K-12 schooling system lack informed views of NOS and that these naïve views have negative repercussions for the acquisition of conceptual knowledge (Ackerson et al., 2000; Ackerson & Abd-El-Khalick, 2005; Gallagher, 1991; Griffiths & Barman, 1995; Khishfe & Abd-El_Khalick, 2002; Moss, Abrams, & Robb, 2001).

Lederman and his colleagues (cf. Lederman et al., 2002) explain that NOS views are distinct from science processes in that they 'consider scientific processes to be activities related to the collection and interpretation of data, and the derivation of conclusions. NOS, by comparison, is concerned with the values and epistemological assumptions underlying these activities' (p. 499). Thus, NOS refers to the foundational qualities of scientific inquiry and argumentation: the tentative and theory-laden nature of scientific knowledge, the creative and imaginative nature of scientific work, and the socially and culturally subjective nature of scientific knowledge and exploration (Lederman et al., 2002). We do not question these tenets, but suggest the importance of investigating on an even deeper level the personal beliefs and associations that may prohibit individuals from fully integrating these NOS tenets into their understanding about science. Thus, we suggest that the acknowledged need for explicit (rather than implicit) teaching of NOS (e.g. Abd-El-Khalick & Ackerson, 2004; Ackerson et al., 2000; Jungwirth, 1970; Meichtry, 1992; Tamir, 1972) may be due to ingrained assumptions or associations that are embedded in a belief system that, once revealed, can be a part of a discursive toolkit for rebuilding a more accurate view of science. What beliefs or associations prevent a student (or teacher) from understanding that imagination and creativity are important aspects of science exploration? A broad review of research about popular views of science revealed three general dimensions that we frame as foundational dimensions of NOS knowledge – static versus dynamic views of science, science as building inventions versus science as building knowledge, and science for a few elite versus science for all.

Static versus dynamic views of science. Static versus dynamic views of science characterize the beliefs generally relating to scientific knowledge; dynamic views reflect the belief that scientific facts are prone to scrutiny and change, whereas static views reflect the notion that scientific knowledge is a steady accumulation of facts that are stable over time. Songer and Linn (1991) administered pre and post *Views of Science Evaluation* to 153 middle school students who participated in a special science program, the Computer as Lab Partner curriculum, which emphasized first-hand inquiry tasks within a collaborative setting. This evaluation consisted of 21 forced-choice and short-answer items targeting students' ideas about scientific knowledge, the work that scientists do, and the NOS learning. These researchers found that of all the respondents, only 15% demonstrated a dynamic view of science. Dynamic views reflect the belief that science is an integral part of one's life and that scientific knowledge is open to criticism and change. A larger percentage (21%) of respondents demonstrated a static view, in which science is 'memorization intensive, and divorced from their everyday lives' (p. 9). The majority (64%) held what the researchers called *mixed beliefs* and argued that the integration of epistemological instruction into a science program can move students with mixed views toward more dynamic views. Similarly, Bajah (1985) found in his large-scale study of students, teachers, and a variety of other types of individuals living in Nigeria that the majority of these individuals, regardless of age or occupation, demonstrated a more static view of science; most respondents believed science was a body of accumulated facts and offered no mention to the methods that scientists use in their work.

Wilensky and Resnick (1999) present several case studies to show how students' misconceptions about the complex and varying levels of scientific explanations hinder their understanding of concepts. Rather than studying a concept in isolation, students should take a systemic approach to learning about phenomena, thus requiring a more dynamic view of science. However, Elby and Hammer (2001) contend that dynamic views should not necessarily disregard scientific facts in that not all scientific knowledge is tentative in nature (e.g. the world is round). Contextual understanding about the dynamic NOS should not necessarily deny the existence of key conceptual knowledge that is a stable foundation for further investigations.

Science as knowledge creation. Ryan and Aikenhead (1992) found in their investigation of views of science among 2000 North American secondary students that students often confuse science with technology; most characterizations of science are related to medical or environmental innovations rather than the accumulation and continual revision of theoretical knowledge about the natural world. Although human innovation may be useful for, or even an outcome of scientific investigation, science is conventionally defined as the accumulation and the occasional restructuring of knowledge about the world (e.g. Kuhn, 1962).

This popular confusion with science and technology has been documented in empirical findings by other researchers (Constantinou, Hadjilouca, & Papadouris, 2010; Custer, 1995; Kang & Wallace, 2005) who attribute this misplaced emphasis on technological innovations to the ways in which popular media frames science in terms of improving conditions for daily living. The portrayal of *scientist as inventor* is prevalent in news reports about breakthroughs in medical products and innovations that improve the standard of living; the exposure to such media may influence the development of this confusion among young viewers.

Science for all. The emotional or attitudinal associations that students have with science can have a powerful effect on ways in which students participate in the science classroom. In his book, *Talking science*, Lemke (1990) provides a detailed, introspective critique of science education by examining the types of discourse (both written and oral) in the science classroom that continually communicate negative or, in his words, 'harmful' attitudes toward science (p. 129). He writes that in science we

> tend to reinforce a special mystique of science, a set of harmful myths that favor the interests of a small elite. That elite does not include science teachers, or even most scientists. It is a *technocratic* elite: managers who try to control decisions by appealing to 'the findings of experts'. (p. 129)

Those who have knowledge about science are made to be geniuses compared to average students, who subsequently experience frustration for not knowing as much. All of us are a part of a culture of learning, and yet the culture of learning in science is generally viewed as an elite practice that has little to no immediate relevance in everyday life (Latour, 1987; Lemke, 1990). In this sense, scientists are considered *superhuman*, possessing the perfect ability to bestow objective knowledge to fledglings (i.e. teachers and students) that strive to comprehend this golden knowledge. Avraamidou and Osborne (2009) seem to echo this sentiment in their argument that this 'picture of science, mysterious and opaque, estranges students … it presents science as dogma – a body of uncontroversial, unquestioned and unequivocal knowledge' (p. 1684). This view of science may be a direct result of the monologic ways in which scientific knowledge is discussed in the classroom.

Chambers (1983) administered the Draw-a-Scientist Test to 4807 elementary students ranging from kindergarten to fifth grade and found that stereotypical images (e.g. male, wearing glasses, lab coats, etc.) were prevalent among most respondents, and that the presence of many of these stereotype images were positively associated with grade level. Chambers also found that many students in the upper grades (i.e. at least one student in every participating classroom) drew signs along with their pictures of scientists, 'bearing such messages as "Keep Out!", "Private," "Do Not Enter," "Go Away," and "Top Secret"' (p. 264). Such sentiments complement Avraamidou and Osborne's (2009) point about the estrangement that many students experience in the science classroom. Findings from a five-year ethnographic study by Moje et al. (2004) suggests that if teachers are willing to take a community-based, dialogic approach to teaching science, then 'science as a Discourse community could lose some of its mystique and privilege' (p. 54).

For this study, we investigated pre- and post-intervention interview responses to investigate the extent to which the CELL program could affect changes in ideas and behaviors related to climate change science. Specifically, we were interested in whether student participants would demonstrate greater understanding of the NOS and evidence-based reasoning about global climate change, and greater awareness of and dispositions toward individual behaviors related to environmental conservation, after the eight-week CELL program.

Method

Participants

A total of 141 youth participants from four classrooms participated in an eight-week iteration of CELL, during which students read and discussed adapted versions of seminal scientific studies related to climate change issues (e.g. rise in sea level; a total of 12 seminal studies were adapted for this program). These classrooms were located in Northern California in the United States ($n = 54$), the southern region of China ($n = 30$), New Zealand ($n = 25$), and Norway ($n = 32$). During weekly classroom discussions, students posed and evaluated arguments about the climate change issues presented in these adapted studies. Following within-class discussions, participants contributed to an online, cross-classroom exchange through an open-source learning platform, with peers from other participating classrooms, and occasionally with one or more of seven volunteer consulting scientists from a variety of fields (i.e. biology, glaciology, wildlife veterinarian science, ecology, physics, and environmental design and sustainability). These consultants were recruited primarily for vetting all materials created for the program, and were invited to join in online discussions and real-time chats if available. All consultants were instructed to limit their discussion contributions to responses in the form of resources and questions that addressed requests and commentary initiated by the student participants.

Of these 141 youth participants, 96 (68% of the total number of participants) were interviewed and completed the behavioral observation task described below both before and after the CELL program. Although we intended to interview all students, the amount of time allotted by site-based teachers varied according to curricular and other school-based constraints. For example, the US teachers expressed their need to maintain the pace of instruction commensurate with other teachers within their department. As such, we were successful in interviewing 30 students from China, 25 students from New Zealand, 29 students from Norway, and 12 students from the USA.

Intervention: the CELL program

CELL provided 13- to 17-year-old students and their teachers with (1) a sustainable set of resources and discussion guides for fostering evidence-based discussions about climate change concepts and issues and (2) online opportunities to connect with students in various parts of the world – China, New Zealand, Norway, and the United States – as well as scientists across different disciplines in order to discuss and evaluate the evidence for global climate change. This design was inspired by a previously implemented project called Global Climate Exchange, led by science education researchers Korsager, Slotta, and Jorde (Korsager & Slotta, 2015; Korsager, Slotta, & Jorde, 2014) who designed was a six-week program that focused on fundamental concepts related to climate change (e.g. greenhouse gases) and how 16- and 17-year-olds in Norway, Sweden, Canada, and China helped one another understand these concepts through explorations of web-based sources and online discussions via a wikisite. This design echoes earlier initiatives in collaborative online science learning by Slotta and colleagues, who have found that online collaboration among peers can have a positive effect on engagement and understanding (e.g. Stagg Peterson & Slotta, 2009; Slotta & Aleahmad, 2009; Slotta & Linn, 2009). A unique aspect of the CELL program is the selection and adaptation of seminal scientific studies that students would read and discuss along with other sources from the respective school curriculum, the Internet, and elsewhere.

The online discussions across the CELL communities were intentionally student-led in that discussion threads always began with a participant's question or comment related to the topic of that given week (e.g. *Isn't* [climate change] *just a way of nature?*). Seven scientists from various fields of study (physics, biology, and environmental science) were recruited to facilitate these online discussions by way of posting follow-up questions or challenges for student participants. Findings from analysis of these online exchanges suggest that the open engagement of socially relevant, unresolved issues was beneficial in fostering a global community across the four sites (Arya & Parker, 2015). Dialogic activities, whether in the classroom or in virtual space, have been found to be beneficial for supporting the development of scientific understanding and reasoning (e.g. Alexander, 2010; Mercer, Dawes, Wegerif, & Sams, 2004; Mercer & Littleton, 2007; Nystrand et al., 1997).

Adapted primary studies and discussion questions. CELL participants read a total of 12 adapted texts, one to two pages in length, which were modified from original studies referenced by the Nobel-winning consortium, the *Intergovernmental Panel on Climate Change* (IPCC, 2010). Providing students with adapted primary literature (APL; i.e. adapted versions of published scientific studies) has been shown to improve student understanding of inquiry methods compared to standard school texts about the same conceptual content (Baram-Tsabari & Yarden, 2005; Falk & Yarden, 2009). Baram-Tsabari and Yarden (2005), for example, found that high school students who read an adapted version of a published scientific study demonstrated stronger levels of inquiry methods compared to those who read the standard school texts of the same conceptual content. These authors attribute the difference in inquiry-based skills to the principle that 'the scientist who did the research is also the one describing it in the article,' which 'closes the gap between public knowledge and the frontiers of scientific inquiry' (p. 404). A similar study by Falk and Yarden (2009) revealed that high school students who read APL texts structured their explanations about the content according to the author's inquiry process. Findings from this study demonstrated the ability of APL texts to give students greater understanding of and appreciation for the first-hand investigations conducted by scientists.

The adapted studies developed and used in the CELL program were bound in topic according to the five key issues considered most critical to climate change (Gleick, et al., 2010): the global rise in temperature, the rise in sea level, the human-induced greenhouse effect, loss of biodiversity, and deforestation. In order to optimize readers' opportunity to understand the historicity of scientific progress, we selected studies that spanned several decades (up to a century) for each of the key issues. This cross-generational display of scientific work provided the opportunity for students to view and discuss the progressive nature of scientific investigations over time, within the context of a single issue such as the steady rise in sea level.

The selected original studies (all published in English) were modified in terms of text length and readability while maintaining original research questions, tables, and figures. The length of an individual text was determined by the extent to which the text (along with other associated texts targeted for a particular reading discussion session) could be read and discussed by most participants within collaborative contexts in less than a 50-minute period, which is the shortest reported duration of class time from the participating classroom sites. The readability goal for any given text is that all key ideas (including data figures and tables) could be understood by all participants within collaborative contexts in which students are encouraged to help one another during discussions with support from teachers as requested or needed. The final versions of each adapted study developed from a four-step iterative process of (1) mapping the original versions (ensuring the inclusion of key concepts and ideas), (2) drafting initial adaptations to be vetted by consulting scientists, (3) eliciting feedback from adolescent youths from an additional classroom in Norway ($n = 24$) who did not participate in the eight-week program (and whose level of English competency would approximate the average competency of CELL participants), and (4) revisions to ensure clarity for readers without losing accuracy of scientific information. This process is based on previous research on science text complexity and quality for youth (Arya, Hiebert, & Pearson, 2011; Arya & Maul, 2012) and the general principles of what counts as a 'considerate text' as presented by Posner, Strike and Peter (2002) who clarify that texts worth reading were developed with attention to the targeted audience, structural coherence, and memorability for readers.

All associated discussion questions for the adapted studies (e.g. *what were the scientists' research questions? what is the main idea of this table?*) were vetted by participating scientists and science educators, and were previewed by the classroom of Norwegian students prior to the eight-week study. These questions helped teachers to lead whole classroom discussions in addition to group interactions. Questions focused on the general structures of published studies (Introduction, Methods, Results, and Discussion) with the goal of fostering an understanding of the genre of and historical differences between scientific publications (Bazerman, 1988). Figure 1 shows an example of an excerpted text and illustration from the adapted version of a study regarding the rise in sea level.

Adapted original scientific studies were introduced to students who read and reflected on reported processes and empirical data through synchronous classroom discussions

Sea-level Fingerprint of Continental Water and Ice Mass Change from GRACE
A study by E.M. Riva, J.L. Bamber, D.A. Lavallée and B. Wouters published in 2010

Adapted from: Riva, R. E. M., J. L. Bamber, D. A. Lavallée, and B. Wouters (2010), Sea-level fingerprint of continental water and ice mass change from GRACE, *Geophys. Res. Lett.*, *37*, L19605, doi:10.1029/2010GL044770.

Physicist Riccardo Riva and his colleagues are studying the general increase in sea level over time. They wanted to learn if the rise in sea level was mostly due to the melting polar ice caps or if runoff of precipitation (rain and snowfall) was the major cause. They decided to use satellite technology, specifically the Gravity Recovery and Climate Experiment satellite (GRACE) to help them find an answer to their question.

From two satellites called "Topex/Poseiden" & "Jason-1," launched in 1992 and 2001 respectively, scientists have already observed a steady increase in sea level. This increase is illustrated in *Figure 1* below.

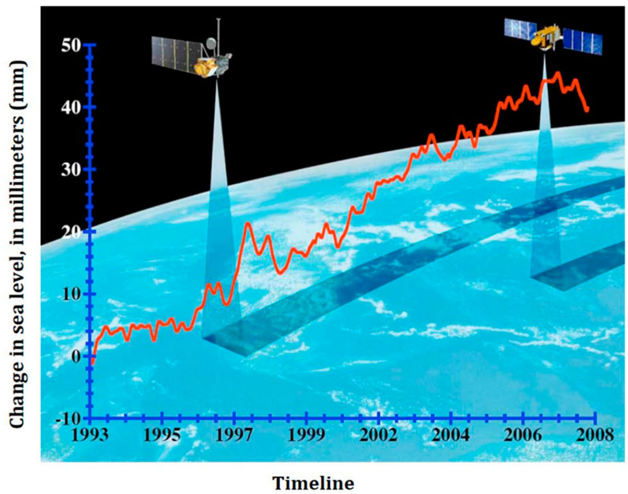

Figure 1. Excerpt of an adapted version of a scientific study.

with immediate, country-specific peers and asynchronous, CMC with peers from the other three countries. During such discussions, participants considered the findings from individual studies and triangulated these findings with other sources suggested by peers, researchers, and (on occasion) the consulting scientists.

As previously mentioned, these texts were not the sole targets of discussions; students were encouraged by participating teachers and program facilitators to bring in other sources of information they deemed relevant to the issues and concepts highlighted in these studies. As such, participants made references to many sources of information that included personal experiences, websites, and blogs from individuals and professional organizations, editorial pieces, and other journalistic accounts.

Data collection

As with the instructional materials, all interview items and associated task materials were vetted by the consulting scientists and piloted with six high school students randomly selected from the aforementioned Norwegian classroom.

Interviews. At both the outset and the completion of the eight-week program, students participated in audio-recorded, semi-structured individual interviews that included two open-ended questions designed to assess participants' (1) knowledge of NOS and (2) command of academic and scientific language. These questions (*What does climate change science mean to you? What do you think climate change scientists do in their work?*) were designed to be open-ended with standard, nonspecific follow-up questions (e.g. *could you tell me more?*); these questions sought to elicit students' understandings about the NOS and the work that scientists do, both in general and specifically with reference to climate change. The interviews were designed to resemble everyday conversations; the interviewing researchers communicated their desire to learn about the participants' views and thinking. This conversational style of interviewing was designed to mitigate some of the adverse educational effects of more formalized or evaluative structures in interviews in academic contexts (e.g. Briggs, 1986; Brinkmann, 2014).

All recorded interviews were transcribed to capture the substantive content of the responses, thus excluding linguistic subtleties such as false starts, self-corrections, changes in tone and volume, pauses, and so forth. Each interview was then coded according to two schemes: one for the extent to which the youth's responses to interview questions demonstrated knowledge of science as a way of knowing (NOS) and a second one for the extent to which the youth's responses demonstrated a command of academic and scientific language. When coding, researchers were blind both to the identity of the student and to whether the interview had taken place prior to or following the eight-week program.

NOS understanding. Each of the (20–30-minute) pre- and post-program interviews, including both interview questions and all follow-up elicitations, was coded separately by two researchers, according to four criteria, each related to whether the student demonstrated a particular form of understanding of NOS principles anywhere in the interview. These were: (1) an understanding of the ever-tentative, iterative process of scientific inquiry (e.g. *scientists go back and try it a different way; sometimes because of better equipment scientists are able to get better answers when they try again*), (2) the principle of replicability (e.g. *they have a question and figure out a way to get an answer so that other scientists can see what they did and judge for themselves if it is correct*), (3) knowledge of processes of consensus-building (e.g. *scientists do their studies and talk together to figure out what is happening*), and (4) notions of evidence-based reasoning (e.g. *we know that our forests are dying because you can see how small the forests are getting over time from that graph* [referring to graphic discussed in class]). These forms of NOS understanding reflect the most widely accepted qualities of science among science educators and educational researchers (e.g. Abd-El-Khalick et al., 2004; Avraamidou & Osborne, 2009; Chambers, 1983; Lemke, 1990; Ryan & Aikenhead, 1992; Songer & Linn, 1991). Thus for each student, there were four opportunities to demonstrate NOS understanding.

The two researchers demonstrated high inter-rater reliability, initially giving the same code to 98% of analyzed responses. The remaining cases were resolved through discussion.

Command of academic and scientific language. In coding for command of academic and scientific knowledge, units of analysis were individual words. The first instance of each word used by a youth in their interview responses was coded according to whether or not it was recognized as 'academic or scientific;' then, the number of unique uses of academic and scientific words was divided by the total number of unique words used, yielding a percentage score for each individual.

In order to determine whether a word should be counted as academic or scientific, we first consulted the *Academic Word List* (AWL; Coxhead, 2000; Coxhead & Hirsch, 2007). This list contains the most frequently featured academic terms such as 'analysis' and 'resolution' as well as words that connote NOS subject matter such as 'hypothesis' and 'evidence.' Additionally, we compiled a list of specific words related to the epistemic NOS, many of which were not on the AWL (e.g. 'measure,' 'argument,' 'support,' and 'database') from previously published NOS assessment items (Billeh & Hasan, 1975; Lederman et al., 2002). If a word appeared on either list, it was coded as being academic or scientific.

Paper task: disposition to conserve. At the beginning of each interview (both prior to and following the eight-week CELL program), the researcher asked the participant to 'please throw away the paper' in reference to a piece of paper that was on the table near the interviewee. The researcher pointed in the general direction of the other end of the room (approximately 10 meters from the interview table) where a trash can and recycling container were placed prior to the interviews. Participants had the option of using the trashcan (which was placed close by and unobstructed) or the recycling bin (which was farther away and partially obstructed). The design of this task was based on the general design of similar tasks conducted by cognitive psychologists who study decision-making practices within the context of climate change science (e.g. Goeschl & Perino, 2012; Masini & Menichetti, 2012).

The result was dichotomously coded according to whether the interviewee threw the paper in the trash can or the recycling bin. The use of the less convenient, but more conservation-minded option of the recycling bin served as a proxy for awareness of climate change issues and a disposition to conserve. Many studies about sustainability practices have focused on recycling as a key aspect of conservation across the world (e.g. Gutberlet, 2012; Hatt, Deletic, & Fletcher, 2006; Hobson, 2006; Hurlimann, Dolnicar, & Meyer, 2009; Zaman & Lehmann, 2011).

Results

Results from the analysis of 96 sets of pre- and post-program interviews revealed evidence of a significant overall shift in focus on the NOS as a way of knowing, including a greater demonstration of the ability to engage in evidence-based reasoning.

With respect to NOS understanding, at pretest, a total of 35 demonstrations (out of 384 possible; 4 opportunities for each of the 96 students) of NOS understanding were observed; at posttest, 54 total demonstrations were observed. This difference was statistically significant ($\chi^2 = 4.59$, df = 1, $p < .05$). Qualitatively, participants appeared to demonstrate an increase in understanding of science as a continual process of evidence-based reasoning and consensus-building (e.g. *scientists test their ideas again and again; they have a question and figure out a way to get an answer so that other scientists can see what they did and judge for themselves if it is correct*) and move away from more politically or ideologically based and less tentative views about scientific work (*climate change is all made-up because it is getting warmer anyway; scientists keep changing their minds; they* [scientists] *give us facts about what is going on*).

With respect to academic language, at pretest, 85 out of a total of 1125 unique words were coded as 'academic or scientific,' whereas at posttest, 117 out of 1114 unique words met this qualification. This difference was also statistically significant ($\chi^2 = 4.94$, df = 1, $p < .05$). In particular, words such as *data, evidence, statistics, observation(s), research,* and *analyze/sis* were observed much more frequently in the post-program interviews.

Finally, 34.4% (33 out of 96) of the students demonstrated a propensity to recycle at pretest, whereas 61.5% (59 out of 96) did so at posttest, an increase of 27.1% ($\chi^2 = 14.1078$, df = 1, $p < .01$).

Discussion

In this study, we aimed to develop a better understanding of the mechanisms though which adolescent youth develop and change understandings about the NOS as a way of knowing, the ability to engage in evidence-based reasoning, understandings of climate change and climate science, and attitudes and behavioral dispositions related to environmental conversation.

Results of the analyses of interviews and the behavioral task suggested that, on average, program participants developed stronger and more sophisticated understandings of science as a way of knowing, greater understandings of climate change and climate science, and greater sensitivity to environmental conservation. This said, the focus of this study was not on causal inference, and the lack of a control group prohibits definitive causal conclusions regarding the unique effect of the CELL program (e.g. relative to other forms of instruction). Furthermore, there is no way of determining with precision which aspects of the CELL program had the greatest impact on changes in student beliefs, understandings, and attitudes.

Findings from this study highlight the importance of fostering evidence-based discussions in science classrooms that involve open-ended, peer-led dialogue in order to encourage authentic engagement with real scientific data. When secondary students have free access to seminal sources of evidence based on continual, recorded observations about global climate change and are encouraged to talk about these sources with peers within and beyond the science classroom, prior ideological notions about science and climate change may give way to more informed ideas about the work of scientists and about the importance of evidence in learning about global climate change. Thus, rather than taking a direct instructional approach to communicating the NOS and scientific data through lectures and didactic texts, students may engage more actively in the construction of NOS knowledge and associated language if given the data along with the time and space to explore such authentic scientific texts with their peers.

While the replicability of the CELL program may be limited considering that scientists are not widely and readably available to participate in such a program, the most valuable aspect of the participants' experience may be the opportunity to interpret and evaluate scientific data with their peers. Students all expressed (at least at one point during the program) concerns about the Earth's changing climate and thoughts concerning their role in mitigating such changes. Through open exchanges with peers within and across the classroom sites, participants were given the freedom to form ideas about the published data, connect this information with their own experiences, and learn about the experiences of others. These findings support those of similar intervention studies that investigated the benefits of student-centered dialogue in classroom learning; Mercer and colleagues (2004), for example, found in their investigation of a primary school program that emphasizing open discussions of shared information and explicit demonstrations of reasoning promoted deeper understandings of science content. Such open exchanges allow for stronger, deeper connections with scientific information, which may in turn help to mitigate the polarization of climate change views based on ideological reasoning among non-specialist populations (Gleick et al., 2010).

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Diana Arya is an assistant professor in the Department of Education. Her research interests focus on the literacy practices and processes within K-12 science classroom and professional communities. Her work is particularly focused on language in use within the intersections of school science curricula, the varied genres of scientific texts, classroom interactions, and how disciplinary knowledge is constructed within the context of the discursive practices of scientists across disciplines.

Andrew Maul is an assistant professor in the Gevirtz Graduate School of Education at the University of California, Santa Barbara. He is broadly interested in the history and philosophy of science, and is particularly interested in the conceptual foundations of research methods in the psychological sciences. His current work focuses on the logic of measurement and the connections between metrology and psychometrics.

References

Abd-El-Khalick, F., & Ackerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education*, *88*(5), 785–810.

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamiok-Naaman, R., Hofstein, A., … Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*, 397–419.

Ackerson, V. L., & Abd-El-Khalick, F. S. (2005). 'How should I know what scientists do? I'm just a kid': Fourth-grade students' conceptions of nature of science. *Journal of Elementary Science Education*, *17*(1), 1–11.

Ackerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, *37*, 295–317.

Alexander, R. (2010). Speaking but not listening? Accountable talk in an unaccountable context. *Literacy*, *44*(3), 103–111.

Alvermann, D. E. (2002). *Adolescents and literacies in a digital world*. New York, NY: Peter Lang.

Applebee, A. N., Langer, J. A., Nystrand, M., & Gamoran, A. (2003). Discussion-based approaches to developing understanding: Classroom instruction and student performance in middle and high school English. *American Educational Research Journal*, *40*(3), 685–730.

Ares, N., & Evans, D. M. (2014). Mathematics and numeracy as social and spatial practice. *Education Research International*, *2014*, 1–14.

Arya, D. J., Hiebert, E. H., & Pearson, P. D. (2011). The effects of syntactic and lexical complexity on the comprehension of elementary science texts. *International Electronic Journal of Elementary Education*, *4*(1), 107–125.
Arya, D. J. & Maul, A. (2012). The role of the scientific discovery narrative in middle school science education: An experimental study. *Journal of Educational Psychology*, *104*(4), 1022–1032.
Arya, D. J. & Parker, J. K. (2015). Dialogic action in climate change discussions: An international study of high school students in China, New Zealand, Norway and the United States. *Dialogic Pedagogy: An International Online Journal*, *3*. doi:10.5195/dpj.2015.53
Attewell, P. (2001). Comment: The first and second digital divides. *Sociology of Education*, *74*(3), 252–259.
August, D., Carlo, M., Dressler, C., & Snow, C. (2005). The critical role of vocabulary development for English langauge learners. *Learning Disabilities Research & Practice*, *20*(1), 50–57.
Avraamidou, L., & Osborne, J. (2009). The role of narrative in communicating science. *International Journal of Science Education*, *31*(12), 1683–1707.
Bailey, A. L. (2007). *The language demands of school: Putting academic English to the test*. New York, NY: Yale University Press.
Bajah, S. T. (1985). A nigerian case study of perceptions of science. *Prospects*, *15*(4), 577.
Baram-Tsabari, A., & Yarden, A. (2005). Text genre as a factor in the formation of scientific literacy. *Journal of Research in Science Teaching*, *42*(4), 403–428.
Barton, D., & Hamilton, M. (1998). *Local literacies: A study of reading and writing in one community*. London: Routledge.
Bazerman, C. (1982). Scientific writing as a social act: A review of the literature of the sociology of science. In P. V. Anderson, J. Brockman, & C. R. Miller (Eds.), *New essays in technical and scientific communication: Research, theory, and practice* (pp. 156–184). Farmingdale, NY: Baywood.
Bazerman, C. (1988). *Shaping written knowledge: The genre and activity of the experimental article in science*. Madison: University of Wisconsin Press.
Billeh, V. Y. & Hasan, O. E. (1975). Factors affecting teachers' gain in understanding the nature of science. *Journal of Research in Science Teaching*, *12*(3), 209–219.
Bomer, K., & Bomer, R. (2001). *For a better world: Reading and writing for social action*. Portsmouth, NH: Heinemann.
Bowker, G. C. (2005). *Memory practices in the sciences*. Cambridge: MIT Press.
Briggs, C. L. (1986). *Learning how to ask: A sociolinguistic appraisal of the role of the interview in social science research (No. 1)*. Cambridge, MA: Cambridge University Press.
Brinkmann, S. (2014). Unstructured and semi-structured interviewing. In P. Leavy (Ed.), *The Oxford handbook of qualitative research* (pp. 277–299). Oxford: Oxford University Press.
Buckler, C., & Creech, H. (2014). *Global monitoring and evaluation report, shaping the future we want*. UN Decade of Education for Sustainable Development (2005–2014).
Cartwright, N. (1983). *How the laws of physics lie*. Oxford: Oxford University Press.
Chambers, D. W. (1983). Stereotypic images of the scientist: The Draw-a-Scientist-Test. *Science Education*, *67*, 255–265.
Common Core Standards Initiative. (2012). *Common core state standards for English language arts & literacy in history/social studies, science, and technical subjects*. Retrieved from http://www.corestandards/org/assets/CCSSI_ELA%20Standards.pdf
Constantinou, C., Hadjilouca, R., & Papadouris, N. (2010). Students' epistemological awareness concerning the distinction between science and technology. *International Journal of Science Education*, *32*(2), 143–172.
Coxhead, A. (2000). A new academic word list. *TESOL Quarterly*, *34*(2), 213–238.
Coxhead, A., & Hirsch, D. (2007). A pilot science-specific word list. Revue Francaise de linguistique appliquee.
Coxhead, A., & Nation, P. (2001). The specialised vocabulary of English for academic purposes. In J. Flowerdew & M. Peacock (Eds.), *Research perspective on English for academic purposes* (pp. 252–267). Cambridge: Cambridge University Press.

Custer, R. L. (1995). Examining the dimensions of technology. *International Journal of Technology and Design Education*, *5*(3), 219–244.

Debell, M., & Chapman, C. (2003). *Computer and internet use by children and adolescents in 2001* (NCES 2004-014). Retrieved from nces.ed.gov/programs/quarterly/vol_5/5_4/2_1.asp

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*(5), 554–567.

Falk, H., & Yarden, A. (2009). 'Here the scientists explain what I said.' Coordination practices elicited during the enactment of the results and discussion sections of adapted primary literature. *Research in Science Education*, *39*, 349–383.

Freire, P., & Macedo, D. (1987). *Literacy: Reading the word and the world*. New York, NY: Routledge.

Gallagher, J. J. (1991). Perspective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education*, *75*, 121–134.

Gee, J. P. (1991). Socio-cultural approaches to literacy (literacies). *Annual Review of Applied Linguistics*, *12*, 31–48.

Gee, J. P. (1996). *Social linguistics and literacies: Ideology in Discourses* (2nd ed.). London: Taylor & Francis.

Gee, J. P. (2005). The new literacy studies: From socially situated to the work. *Situated Literacies: Reading and Writing in Context*, *2*, 177–194.

Giere, R. (1988). *Explaining science*. Chicago, IL: University of Chicago Press.

Gleick, P. H., Adams, R. M., Amasino, R. M., Anders, E., Anderson, D. J., Anderson, W. W., … Bax, A. (2010). Letters: Climate change and the integrity of science. *Science Magazine*, *328*(5979), 689–690.

Goeschl, T., & Perino, G. (2012). Instrument choice and motivation: Evidence from a climate change experiment. *Environmental and Resource Economics*, *52*(2), 195–212.

Griffiths, A. K., & Barman, C. R. (1995). High school students' views about the nature of science: Results from three countries. *School Science and Mathematics*, *95*, 248–356.

Gutberlet, J. (2012). *Recovering resources-recycling citizenship: Urban poverty reduction in Latin America*. Farnham: Ashgate.

Gutierrez, K., Baquedano-Lopez, P., & Tejaeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, Culture, and Activity*, *64*, 286–303.

Hamilton, L. C. (2011). Education, politics and opinions about climate change evidence for interaction effects. *Climatic Change*, *104*(2), 231–242.

Hart, P. S., Feldman, L., Leiserowitz, A., & Maibach, E. (2015). Extending the impacts of hostile media perceptions influences on discussion and opinion polarization in the context of climate change. *Science Communication*, *37*(4), 506–532.

Hatt, B. E., Deletic, A., & Fletcher, T. D. (2006). Integrated treatment and recycling of stormwater: A review of Australian practice. *Journal of Environmental Management*, *79*(1), 102–113.

Hicks, D. (1996). Contextual inquiries: A discourse-oriented study of classroom learning. In D. Hicks (Ed.), *Discourse, learning, and schooling* (pp. 104–144). New York, NY: Cambridge University Press.

Hoadley, C. M., & Enyedy, N. (1999). Between information and communication: Middle spaces in computer media for learning. In C. Hoadley & J. Roschelle (Eds.), *Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999*. ACM Digital Library. Retrieved from http://dl.acm.org/citation.cfm?id=1150270

Hobson, K. (2006). Bins, bulbs, and shower timers: On the 'techno-ethics' of sustainable living. *Ethics Place and Environment*, *9*(3), 317–336.

Hurlimann, A., Dolnicar, S., & Meyer, P. (2009). Understanding behaviour to inform water supply management in developed nations – a review of literature, conceptual model and research agenda. *Journal of Environmental Management*, *91*(1), 47–56.

Intergovernmental Panel on Climate Change (IPCC). (2010). Retrieved from http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

Jewitt, C. (2008). Multimodality and literacy in school classrooms. *Review of Research in Education*, *32*(1), 241–267.

Jungwirth, E. (1970). An evaluation of the attained development of the intellectual skills needed for "understanding of the nature of scientific enquiry" by BSCS pupils in Israel. *Journal of Research in Science Teaching*, *7*(2), 141–151.
Kalantzis, M., & Cope, B. (1997). *Multiliteracies: Rethinking what we mean by literacy and what we teach as literacy [in] the context of global cultural diversity and new communications teachnologies*. Haymarket: Centre for Workplace Communication and Culture.
Kang, N. H. & Wallace, C. S. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. *Science Education*, *89*(1), 140–165.
Khishfe, R., & Abd-El_Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, *39*(7), 551–578.
Knobel, M. (2001). "I'm not a pencil man": How one student challenges our notions of literacy "failure" in school. *Journal of Adolescent & Adult Literacy*, *44*(5), 404–414.
Korsager, M., & Slotta, J. D. (2015). International peer collaboration to learn about global climate changes. *International Journal of Environmental & Science Education*, *10*(5), 717–736.
Korsager, M., Slotta, J. D., & Jorde, D. (2014). Global climate exchange: Peer collaboration in a "global classroom." *Nordic Studies in Science Education*, *10*(1), 105–120.
Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom*. London: Continuum.
Krueger, J. (2000). Distributive judgments under uncertainty: Paccioli's game revisited. *Journal of Experimental Psychology: General*, *129*, 546–558. doi:10.1037/0096-3445.129.4.546
Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago.
Lankshear, C., & Knobel, M. (2011). *New literacies*. Maidenhead: McGraw-Hill Education.
Latour, B. (1987). *Science in action*. Cambridge, MA: Harvard University Press.
Latour, B., & Woolgar, S. (1979). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Princeton University.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.
Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331–359.
Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of research in Science Teaching*, *39*(6), 497–521.
Lemke, J. (1990). *Talking science: Language learning, and values*. Norwood, NJ: Ablex.
Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, *38*(3), 296–316.
Lewis, C. (2001). *Literary practices as social acts: Power, status, and cultural norms in the classroom*. Mahwah, NJ: Erlbaum.
Martin, J. R. & Halliday, M. A. K. (1993). *Writing science*. London: Falmer Press.
Masini, A., & Menichetti, E. (2012). The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. *Energy Policy*, *40*, 28–38.
Meichtry, Y. J. (1992). Influencing student understanding of the nature of science: Data from a case of curriculum development. *Journal of Research in Science Teaching*, *29*(4), 389–407.
Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal*, *30*(3), 359–377.
Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. New York, NY: Routledge.
Moje, E. B., Ciechanowski, K. M., Kramer, K., Elllis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and discourse. *Reading Research Quarterly*, *39*(1), 38–70.
Moje, E. B., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is 'quality'?": Language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching*, *38*(4), 469–498.

Moss, D. M., Abrams, E. D., & Robb, J. (2001). Examining student conceptions of the nature of science. *International Journal of Science Education*, *23*(8), 771–790.
Nersessian, N. J. (1999). Model-based reasoning in conceptual change. In L. Magnani, N. J. Nersessian, & P. Thagard (Eds.), *Model-based reasoning in scientific discovery* (pp. 5–22). New York, NY: Kluwer Academic/Plenum.
New London Group. (2000). A pedagogy of multiliteracies designing social futures. In B. Cope & M. Kalantzis (Eds.), *Multiliteracies: Literacy learning and the design of social futures* (pp. 9–38). New York, NY: Routledge.
NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.
Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*, 224–240.
Norris, S. P., Phillips, L. M., & Osborne, J. (2007). Scientific inquiry: The place of interpretation and argumentation. In J. Luft, R. L. Bell, & J. Gess-Newsome (Eds.), *Science as inquiry in the secondary setting* (pp. 87–98). Arlington, VA: NSTA Press.
Nystrand, M., Gamoran, A., Kachur, R., & Prendergast, C. (1997). *Opening dialogue: Understanding the dynamics of learning and teaching in the English classroom*. New York, NY: Teachers College Press.
O'Brien, D. G., Stewart, R. A., & Moje, E. B. (1995). Why content literacy is difficult to infuse into the secondary school: Complexities of curriculum, pedagogy, and school culture. *Reading Research Quarterly*, *30*(3), 442–463.
Organization for Economic Cooperation and Development (OECD). (2012). *Program for International Student Assessment* (*PISA*). Technical report. PISA: OECD.
Pahl, K., & Roswell, J. (2005). *Understanding literacy education: Using new literacies in the elementary classroom*. Los Angeles, CA: Sage.
Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science*, *328*(5977), 459–463.
Posner, G. J., Strike, K. A., & Peter, W. (2002). Considerate text. *Literacy in America: NZ*, *2*, 167–199.
Reich, J., Murmane, R., & Willett, J. (2012). The state of wiki usage in k-12 schools: Leveraging web 2.0 data warehouses to assess quality and equity in online learning environments. *Educational Researcher*, *41*(1), 7–15.
Ryan, A. G., & Aikenhead, G. S. (1992). Students' preconceptions about the epistemology of science. *Science Education*, *76*(6), 559–580.
Sanjek, R. (1993). Anthropology's hidden colonialism: Assistants and their ethnographers. *Anthropology Today*, *9*(2), 13–18.
Slotta, J. D., & Aleahmad, T. (2009). WISE technology lessons: Moving from a local proprietary system to a global open source framework. *Research and Practice in Technology Enhanced Learning*, *4*(2), 169–189.
Slotta, J. D., & Linn, M. C. (2009). *WISE science: Web-based inquiry in the classroom*. New York, NY: Teachers College Press.
Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, *28*(9), 761–784.
Southerland, S. A., Smith, L. K., Sowell, S. P., & Kittleson, J. M. (2007). Resisting unlearning: Understanding science education's response to the United States' national accountability movement. *Review of Research in Education*, *31*(1), 45–77.
Snow, C. E. (2010). Academic language and the challenge of reading for learning about science. *Science*, *328*(5977), 450–452.
Sørvik, G. O., Blikstad-Balas, M., & Ødegaard, M. (2015). 'Do books like these have authors?' New roles for text and new demands on students in integrated science-literacy instruction. *Science Education*, *99*(1), 39–69.
Stagg Peterson, S., & Slotta, J. (2009). Saying yes to online learning: A first-time experience teaching an online graduate course in literacy education. *Literacy Research and Instruction*, *48*(2), 120–136.

Stahl, S. A. (2003). Vocabulary and readability: How knowing word meanings affects comprehension. *Topics in Language Disorders*, *23*(3), 241–247.
Street, B. (1995). *Social literacies: Critical perspectives on literacy in development, ethnography and education*. New York, NY: Routledge.
Street, B. (2003). What's 'new' in new literacy studies? Critical approaches to literacy in theory and practice. *Current Issues in Comparative Education*, *5*(2), 77–91.
Tamir, P. (1972). Understanding the process of science by students exposed to different science curricula in Isreal. *Journal of Research in Science Teaching*, *9*(3), 239–245.
Unsworth, K. L., & Fielding, K. S. (2014). It's political: How the salience of one's political identity changes climate change beliefs and policy support. *Global Environmental Change*, *27*, 131–137.
Wals, A. E. (2012). *Shaping the education of tomorrow: 2012 full-length report on the UN decade of education for sustainable development*. Paris: UNESCO.
Wertsch, J. (2002). *Voices of collective remembering*. New York, NY: Cambridge University Press.
Whitemarsh, L. (2011). Scepticism and uncertainty about climate change: Dimensions, determinants and change over time. *Global Environmental Change*, *21*(2), 690–700.
Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, *8*(1), 3–19.
Zaman, A. U., & Lehmann, S. (2011). Urban growth and waste management optimization towards 'zero waste city'. *City, Culture and Society*, *2*(4), 177–187.