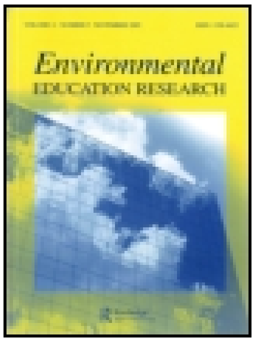

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Identifying effective climate change education strategies: a systematic review of the research

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ABSTRACT

Increased interest in climate change education and the growing recognition of the challenges inherent to addressing this issue create an opportunity to conduct a systematic review to understand what research can contribute to our ideas about effective climate change education. An academic database, EBSCO*host*, was used to identify 959 unique citation records addressing climate change education. Of these, 49 sources met the criteria of focusing on assessment of climate change education interventions. Analysis of these sources examined the intervention purpose, assessment methodology, and identified strategies that might result in effective interventions. Two themes were identified that are common to most environmental education: (1) focusing on personally relevant and meaningful information and (2) using active and engaging teaching methods. Four themes specific to issues such as climate change were also generated: (1) engaging in deliberative discussions, (2) interacting with scientists, (3) addressing misconceptions, and (4) implementing school or community projects. Suggestions for addressing controversial topics like climate change are offered.

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Climate change; environmental education; systematic review

Interest in education about climate change has increased in recent years, attributable in part to expanded funding and leadership for educational programs that address climate change (Anderson 2012; Government of Alberta 2017; UNESCO 2009; U.S. Department of State 2014), the addition of climate change to educational curriculum guidelines (e.g. NRC 2012), mounting awareness of unusual weather patterns (Trenberth, Fasullo, and Shepherd 2015), and the deepening concern of the likelihood of global environmental, social, and economic changes due to climate change (Adger et al. 2013; Bellard et al. 2012; Moorhead 2009; NRC 2001; Wheeler and von Braun 2013). With this growing interest has come an increase in published research articles about climate change education around the world: from 12 articles published between 1990 and 1999, and 433 from 2000 to 2009, to 1489 from 2010 to 2015, according to searches conducted in Academic Search Premier using the search terms of 'climate change' and 'education.' Despite this enormous wealth of information, educators are faced with many challenges when teaching about climate change and there is not broad agreement about what strategies are most effective. The purpose of this research is to use a systematic review to synthesize the existing literature to describe educational strategies that have been shown to contribute to effective teaching about climate change in formal and non-formal settings.

Several aspects of climate change make it a challenging topic to teach. While educators attempt to convey accurate information through school programs, Extension programs, and non-formal venues,

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misconceptions about the causes of climate change abound (Chen 2011; Choi et al. 2010; Sterman 2011) and most youth do not understand basic climate science (Leiserowitz, Smith, and Marlon 2011; Shepardson et al. 2009; Taber and Taylor 2009). Realizing this, many secondary science educators believe their job is limited to conveying factual information about climate science. Others intend to build critical thinking skills and help youth understand the sources of conflict about climate change or prioritize problem solving skills as they help youth conduct local projects to mitigate and adapt to climate changes (Hudson 2001). Still others engage in interventions that acknowledge the psychosocial, evolutionary, and ethical aspects of climate change (Brownlee, Powell, and Hallo 2013; Grady-Benson and Sarathy 2015; Harris 2009).

The distinction between 'just the facts' and 'also the actions' may separate some science educators from environmental educators, but also may highlight the point at which educators believe a fundamental science topic becomes political, and therefore too close to advocacy for classroom educators to address. While social change is at the core of environmental education's mission (UNESCO 1978), it is challenging for some K-12 educators to address, hence the variation in goals from scientific facts to problem solving skills, action competence, and advocacy (Mappin and Johnson 2005; McNeal, Petcovic, and Reeves 2017; Stevenson 2007).

There is also recognition among educators and researchers that how we approach climate change might be different from other environmental issues. Certainly, the complexity and uncertainty of the topic requires careful thought and attention, but even more than ethical controversies about hazardous waste placement or plummeting biodiversity, the topic of climate change seems to deeply resonate with held values, such that adults respond by protecting their group identity and way of life. One outcome is the tendency to seek and recall information that reinforces one's initial judgment (i.e. confirmation bias), creating cultural cognition (Haidt 2012; Kahan 2010; Kinder 1998; McCright and Dunlap 2011; Nickerson 1998), which compels people to protect their group identity, follow their group leaders, and discount information that conflicts with their group's position (Kahan 2010). Therefore, designing and implementing programs about climate change may require a balancing act of increasing knowledge of climate change and acknowledging how cultural ideology plays a role in perception and learning (Guy et al. 2014). Exactly how this can be accomplished is beyond the scope of this paper, but identifying whether literature points to some useful strategies was the goal.

Beyond the challenges associated with the complex nature of climate change, educators working with various audiences, from youth in schools to adults in communities, report additional barriers to providing effective climate change education. Teachers express concern about parents' responses to climate change, making them hesitant to teach about the topic (Wise 2010). Some educators have expressed concern that addressing climate change in their community could decrease their credibility and effectiveness (Morris et al. 2014; Tyson 2014) and so they avoid talking about climate change (Bowers, Monroe, and Adams 2016; Sommers 2014; Wojcik et al. 2014). In addition, some educators feel that they lack the necessary skills and knowledge to adequately deliver instruction regarding climate change (Monroe, Oxarart, and Plate 2013; Plutzer et al. 2016; Prokopy et al. 2015).

The increasing interest in and need for effective climate change education, and increasing awareness that we may not know how best to do it, combine to create an appropriate opportunity to conduct a systematic review to understand effective strategies in climate change education. There is a limit to looking to previously published work to identify strategies for the future. Yet there is also wisdom to being informed about what has been done before embarking on new efforts. Other researchers have embarked on similar tasks in recent years, reviewing existing literature on climate change communication and education (Wibeck 2014), teacher professional development (Hestness et al. 2014), global warming education (Bozdoğan 2011), climate change beliefs and attitudes (Brownlee, Powell, and Hallo 2013), and factors influencing changes in skills, attitudes, and behaviors (Anderson 2012). This review differs from those mentioned as it focuses on articles that tested, measured, and reported results of a climate change educational intervention and used the systematic review process (see Methods). All of these efforts serve to guide educators as they continue to explore new approaches, gaps, and needs in climate change education.[1]

Methods

A systematic review follows specific steps to produce results that are replicable (Cooper 2010; Gough, Oliver, and Thomas 2012). Borrowed from researchers in health and medicine, systematic reviews are not without their detractors (e.g. Evans and Benefield 2001), but do offer a chance to explore, survey, question, and improve the field's published evidence. Systematic reviews help avoid the trap of cherry-picking, where a small number of studies are chosen for their support of predefined conclusions, creating a weak evidence base that may not hold up to scrutiny from funders and other stakeholders.

Literature search and review

To conduct the review, we selected an academic search engine, EBSCO*host*, which offers a single interface to search multiple databases. The number of databases searched by EBSCO*host* varies depending on the institution through which you gain access; we used the University of Florida's library subscription, which at the time (November 2015), searched 76 databases, including Academic Search Premier, Education Full Text, GreenFILE, and PsychINFO.

The selection of search terms is a balance between keeping the search broad enough to capture relevant material but narrow enough to make the review process manageable. Preliminary searches with combinations of different terms informed the selection of final search terms displayed in Figure 1. We limited the results to sources published in English and did not limit the time period of publication.

Entering the search terms in the EBSCO*host* database as an unqualified search (meaning the database searched the title, abstract, subject, keywords, and author) resulted in 1,091 citation records. We imported the results into Zotero, a bibliographic management program, and removed 132 duplicate records, leaving 959 citation records for the first round of review. Although the search identified abstracts that contained appropriate words in the given search fields, all the records did not answer the research question. A decision tree was created and tested to exclude sources that did not assess a climate change education intervention (Figure 2). Team members reviewed random subsets of abstracts until they reached 100% agreement on using the decision tree to determine whether to include the paper.

In the first round of review, each of the 959 abstracts was read by at least two team members. Using the decision tree, we marked 886 records as 'exclude.' Many of the excluded records explained that climate change education was important or suggested how it could be accomplished rather than reporting on a tested educational intervention. In addition to records that failed to meet the criteria of the decision tree, records were excluded if they were book reviews or non-English sources, or if we could not locate full text. The few dissertations that were identified in EBSCO*host* were excluded because we had not done a thorough search for relevant dissertations.

'climate change' OR 'global warming'

AND

'environmental education' OR 'education for sustainability' OR 'education for sustainable development' OR 'conservation education' OR 'climate change education' OR 'climate education' OR 'sustainability education' OR 'ecology education' OR 'energy education' OR 'adult education' OR 'community education' or 'non-formal education' OR 'informal education' OR 'public education'

Figure 1. Search terms used in Ebsco*host* database.

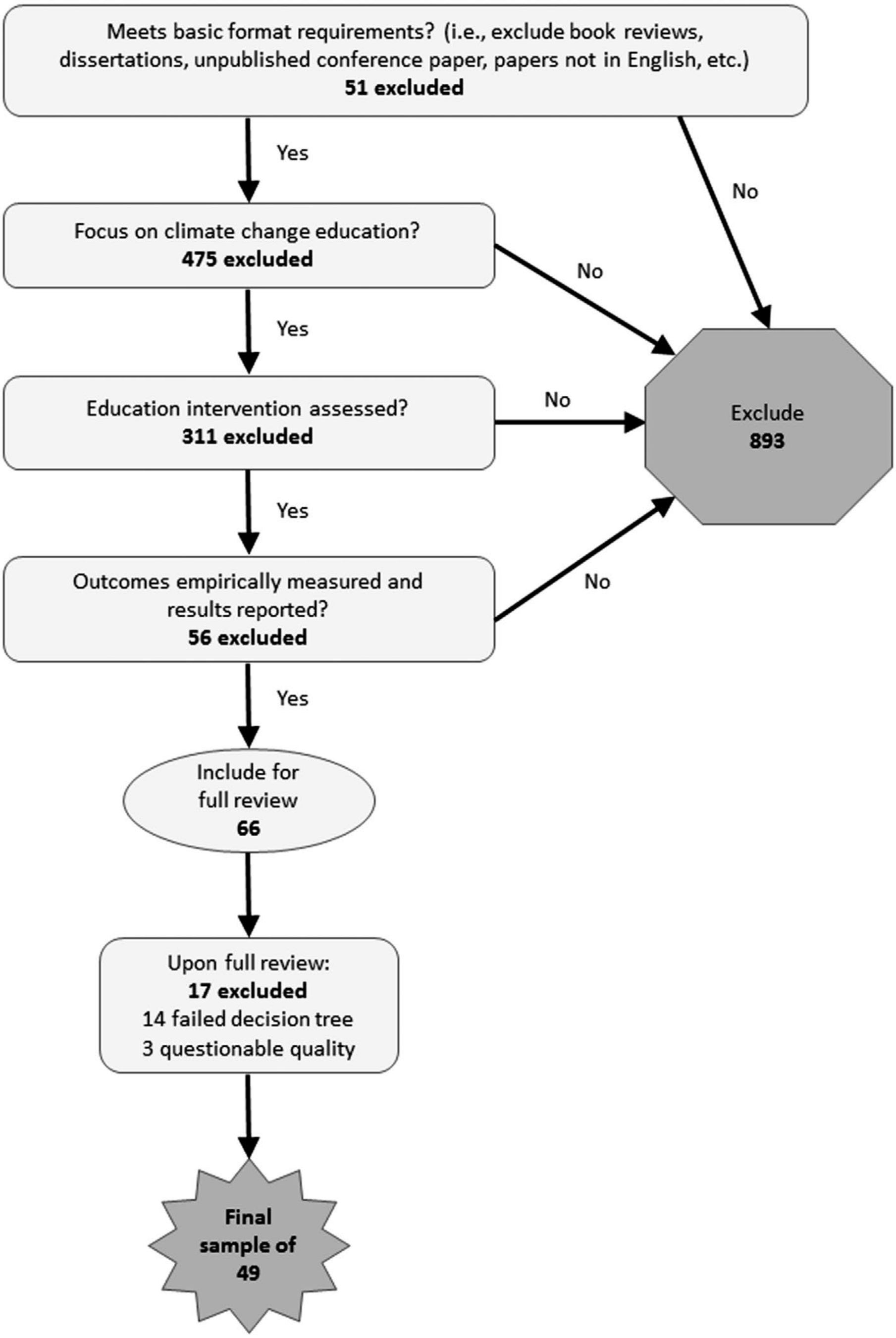

Figure 2. Vetting process and results.

The second round of review involved multiple team members reading each article. The lead author read all 66 publications; each other team member read 33 publications, so that each article was read in its entirety by three people. Decisions and comments were tracked in a spreadsheet, and each article was discussed and evaluated for inclusion in the final set, ultimately composed of 48 peer-reviewed articles and 1 book chapter.

Limitations of the review

Our search process excluded several potential sources of information about effective climate change education strategies. We sought only resources published in English and in the peer-reviewed literature captured in EBSCO*host*. Many researchers around the world publish in English as well as their native language, but we acknowledge this limitation. We also did not access gray literature such as conference proceedings, dissertations, theses, and evaluation reports, which can be problematic to search efficiently. Given that our review relied solely on academic database searching, relevant research that did not use the exact search terms we employed would have not been captured. Despite missed contributions, we believe our findings are based on a diverse enough sample to offer meaningful insight and implications.

The basic assumption of this study, however, is another limitation. We have attempted to identify effective climate change education by looking at evaluated interventions. We are relying on the authors (who are sometimes also the program developers, educators, and evaluators) to describe what made their program effective. Additionally, evaluation studies are often not published in the peer-reviewed literature unless they also include more generalizable research findings, making the orientation of the articles less about the climate change education intervention's assessment and more about a specific strategy or comparison. There is also an extensive body of literature where interventions are not tested and measured that we did not include in this review. These studies also share powerful insights into how people learn about climate change, the barriers to understanding climate change, and the educational strategies that might be useful, and could be the focus of another review. A synthesis of these types of publications could expand the idea of what climate change education is and could be, and provide useful insights into innovative ways to think about instructional strategies.

Analysis

Team members recorded information about the intervention, the evidence regarding the effectiveness of the intervention, and the authors' conclusions, if any, regarding why the intervention was effective. The programs were so varied that there is no simple answer to the question of how to effectively convey climate change. Nor can these programs be readily compared. For example, some were short interventions (a field trip, a festival exhibit) while others were multi-week units. Some were part of a university course, and others reported on entire courses. Thus our goal was to search for common denominators and themes that these authors described (Gough, Oliver, and Thomas 2012).

The lead author identified an initial list of themes regarding how different educational strategies were effectively used to teach about climate change. Other team members contributed to and corroborated the fluid list of themes. Given that each member of the research team has previously been involved in climate change education (both as practitioners and researchers), we acknowledge that our identification of themes likely built on our past experiences and knowledge of the literature (Corbin and Strauss 2015). We discussed the emerging themes, noting which had substantial support and refining themes as needed. The resulting themes best capture the diversity of programs and findings and give each article a theme to connect to, though some articles and themes offer more insightful discussion about why these strategies are effective. We discuss these themes in the following sections; only themes with substantial support in the reviewed literature are presented.

Results

Demographics

Of the 49 contributions (Table 1), the majority involved teaching students in primary or secondary schools (n = 28) or colleges and universities (n = 11). Within the school-based programs, the youngest students were in a third/fourth split class (age 9), but elementary programs were not typical. All but two school-based programs occurred in the classroom; a botanical garden and an assembly auditorium

Table 1. Overview of 49 studies selected for final inclusion in the systematic review.

		Audience					Setting				Outcomes assessed		
Citation	Location	Grades K-5	Grades 6–8	Grades 9–12	College	Adults	School based	University	Teacher workshop	Informal	Knowl-edge	Attitudes	Behavior
Alexandar and Poyyamoli (2012)	India		X				X				X	X	X
Baker, Loxton, and Sherren (2013)	Canada	X					X				X	X	
Bofferding and Kloser (2015)	United States		X	X			X				X		
Chauhan et al. (2009)	England					X				X	X		X
Cone et al. (2012)	United States					X				X	X		
Cordero, Marie Todd, and Abellera (2008)	United States				X			X			X		X
Cox, Kelly, and Yetter (2014)	United States				X			X			X		
Dresner (1989)	United States				X			X				X	
Faria et al. (2015)	United States			X		X			X	X	X	X	
Flora et al. (2014)	United States			X			X				X	X	X
George et al. (2009)	Australia					X				X			X
Gold et al. (2015)	United States		X	X			X						X
Hallar, McCubbin, and Wright (2011)	United States	X	X				X				X	X	
Holthuis et al. (2014)	United States		X	X			X				X		
Jin, Zhan, and Anderson (2013)	United States	X	X	X			X				X		
Karpudewan, Roth, and Abdullah (2015)	Malaysia	X					X				X	X	
Karpudewan, Roth, and Chandrakesan (2015)	Malaysia			X			X				X		
Klosterman and Sadler (2010)	United States			X			X				X		
Lambert and Bleicher (2014)	United States				X			X			X		
Lambert, Lindgren, and Bleicher (2012)	United States				X	X		X			X		
Lee et al. (2013)	United States				X	X				X	X	X	X
Leigh (2009)	England	X	X	X			X						X
Lester, Ma, and Lee (2006)	United States	X					X				X		X
Liu et al. (2015)	United States					X			X		X	X	
Mason and Santi (1998)	Italy	X					X				X		
McNeal, Hammerman, et al. (2014)	United States					X				X	X	X	
McNeal, Libarken, et al. (2014)	United States			X			X				X		

Mutlu and Tokcan (2013)	Turkey				X			X			X		
Nam and Ito (2011)	United States				X			X			X	X	X
Niebert and Gropengiesser (2013)	Germany			X			X				X		
Öhman and Öhman (2013)	Sweden			X			X				X		
Oluk and Özalp (2007)	Turkey		X				X				X	X	
Otieno et al. (2014)	Germany				X			X			X	X	
Porter, Weaver, and Raptis (2012)	Canada		X				X				X		
Pruneau et al. (2003)	Canada		X				X				X	X	X
Pruneau, Doyon, Langis, et al. (2006)	Canada	X	X	X			X						X
Pruneau, Doyon, Vasseur, et al. (2006)	Canada					X			X				X
Reinfried, Aeschbacher, and Rottermann (2012)	Switzerland		X				X				X	X	
Robelia, Greenhow, and Burton (2011)	United States					X				X	X		X
Rooney-Varga et al. (2014)	United States				X			X			X	X	
Sellmann and Bogner (2013a)	Germany			X			X					X	
Sellmann and Bogner (2013b)	Germany			X			X				X	X	
Stapleton (2015)	South Asia			X						X		X	X
Svihla and Linn (2012)	United States		X				X				X		
Theobald et al. (2015)	United States				X			X			X		X
Varma and Linn (2012)	United States		X				X				X		
Vethanayagam and Hemalatha (2010)	India		X	X			X				X		
Zhao et al. (2014)	United States					X				X	X		
Zografakis, Menegaki, and Tsagarakis (2008)	Greece	X	X	X		X	X						X

also served as locations for the interventions. Seven papers involved youth outside of school (such as summer programs) or training programs for in-service or pre-service teachers. Other papers are notable because they are outside the student/teacher/curriculum arena: an exhibit with information about energy conservation at a religious festival, a workshop for local decision makers, training for agricultural consultants, an online game or app for adults, and televised weather explanations. Just over half of the authors conducted their research in the United States (n = 26), with the remaining authors writing of work on four continents.

Purpose and assessment of the intervention

The papers ranged in focus from curriculum evaluation (Bofferding and Kloser 2015; Gold et al. 2015; Hallar, McCubbin, and Wright 2011; McNeal, Libarkin, et al. 2014; Varma and Linn 2012) to tests of specific methods or strategies (Mutlu and Tokcan 2013; Oluk and Özalp 2007; Porter, Weaver, and Raptis 2012; Pruneau et al. 2003; Reinfried, Aeschbacher, and Rottermann 2012; Rooney-Varga et al. 2014; Theobald et al. 2015; Vethanayagam and Hemalatha 2010). Several were designed to provide insights into science education teaching techniques which could have used any content area, but happened to select climate change topics for its complexity or misconceptions (Holthuis et al. 2014; Jin, Zhan, and Anderson 2013; Karpudewan, Roth, and Chandrakesan 2015; Klosterman and Sadler 2010; Lester, Ma, and Lee 2006; Mason and Santi 1998; Otieno et al. 2014).

For 40 of the 49 articles, the programs described were designed to improve knowledge about climate change (Table 1) and authors measured this knowledge change as part or all of their assessment. Most assessed increased understanding about climate science or the causes of and solutions to climate change. Some interventions sought to change attitudes about the importance of climate change (e.g. Faria et al. 2015; Flora et al. 2014; Liu et al. 2015), empower action taking by assessing willingness to engage (e.g. Alexandar and Poyyamoli 2012; Chauhan et al. 2009; Cordero, Todd, and Abellera 2008; Lester, Ma, and Lee 2006; Pruneau, Doyon, Langis, et al. 2006; Stapleton 2015), or encourage selected behaviors (e.g. Flora et al. 2014; Leigh 2009; Pruneau, Doyon, Vasseur, et al. 2006; Robelia, Greenhow, and Burton 2011; Zografakis, Menegaki, and Tsagarakis 2008).

Authors used a variety of tools and indicators to assess effectiveness. Several authors developed pre/post tests of climate knowledge and attitudes to evaluate their particular program (Cordero, Todd, and Abellera 2008; Hallar, McCubbin, and Wright 2011; McNeal, Hammerman, et al. 2014; McNeal, Libarkin, et al. 2014; Nam and Ito 2011). Other studies reported using tools that had been validated by their own team, such as the Global Warming Success Test (Mutlu and Tokcan 2013) and the Climate Science Inventory of Knowledge (Lambert and Bleicher 2014). Some researchers used tools that had been validated by others, such as the Six Americas survey (Leiserowitz et al. 2013; Maibach, Roser-Renouf, and Leiserowitz 2009) to assess perceptions of climate change to determine if the educational intervention shifted attitudes (Flora et al. 2014; Holthuis et al. 2014; Liu et al. 2015; Rooney-Varga et al. 2014), a true/false test of knowledge (Taber and Taylor 2009), and the 2MEV scale to measure environmental attitudes (Sellmann and Bogner 2013a). The New Environmental Paradigm Scale for Children was used (Karpudewan, Roth, and Abdullah 2015; Liu et al. 2015) to assess general attitudes toward the environment. In addition to measuring change in knowledge, surveys and interviews were also used to assess changes in efficacy (Dresner 1989), environmental identity (Stapleton 2015), and the value of using concept maps and influence diagrams to make thinking more visible (Cone et al. 2012).

Some researchers used a variety of tools to understand what occurred in the classroom: assessment tools included observations, interviews, focus groups, emails from teachers, student journals, and student work samples (e.g. Holthuis et al. 2014; Jin, Zhan, and Anderson 2013; Karpudewan, Roth, and Abdullah 2015; Karpudewan, Roth, and Chandrakesan 2015; Klosterman and Sadler 2010; Lester, Ma, and Lee 2006; Mason and Santi 1998; Oluk and Özalp 2007; Svihla and Linn 2012). Many of these researchers were seeking to understand how students came to develop their ideas and many formed the basis of our exploration into effective strategies. Eye-tracking data supplemented a pre/post survey and teacher interviews to help McNeal, Libarkin, et al. (2014) assess online curricula materials. Holthuis et al. (2014) documented the level of student interaction with their Student Engagement Instrument and observations. Baker, Loxton, and Sherren (2013) analyzed artwork created by elementary students studying climate. Lambert and Bleicher (2014) and Liu et al. (2015) used student reflection journals and photo elicitation interviews to assess how participants understood climate change concepts. Student performance was measured by documenting energy savings in schools (Leigh 2009) and by tracking changes in behavior (Pruneau, Doyon, Langis, et al. 2006; Pruneau, Doyon, Vasseur, et al. 2006). Some authors assessed the value of interventions with adults using journals, blogs, and self-assessments from participants to describe valuable contributions and promising strategies (Lambert and Bleicher 2014; Lee et al. 2013; Liu et al. 2015). Reflections from different stakeholders who were involved in the process of developing instructional materials helped Gold et al. (2015) document the quality of the process.

Themes of effective climate change education

Two themes identified as strategies that increased program success are, in fact, common to many environmental education programs on any topic (NAAEE 2004, 2010).

(1) The programs focused on making climate change information *personally relevant and meaningful* for learners.
(2) The activities or educational interventions were designed to *engage learners*.

Personally relevant and meaningful

Climate change communicators suggest that it is important to make the distant, global, and nebulous threat of climate change personally relevant (CRED 2009; Dilling and Moser 2007; Wibeck 2014) and several articles reported on educational interventions that did so. For example, climate change information was embedded in a unit on water quality for middle school students in coastal India, using students' awareness of the importance of clean water to generate a reason to understand current climate impacts on water quality (Alexandar and Poyyamoli 2012). Similarly, decision makers in coastal Oregon were engaged in increasing resilience to climate change in their communities, not a fictitious location (Cone et al. 2012), and Extension professional participants in Australia learned how to apply their new skills to develop climate risk management strategies for business owners in their areas (George et al. 2009). Students interacted with scientists at a nearby laboratory to explore weather and climate on the local mountain and collect data (Hallar, McCubbin, and Wright 2011). Implementing an energy conservation project in their own school supplemented a unit on energy and climate change in the United Kingdom (Leigh 2009). Teenagers carried out a local study of climate change to gather evidence of change and predict impacts (Pruneau et al. 2003). Several programs incorporated a carbon calculator to help learners think about ways they generate carbon emissions and could possibly mitigate climate change (Chauhan et al. 2009; Cordero, Todd, and Abellera 2008).

Recognizing that the impacts of climate change are more obvious elsewhere in the world (such as the polar regions), some researchers investigated the effect of local contexts on learning. Students in California learned most about adaptations that responded to personal threats due to climate change, such as rising sea level (Bofferding and Kloser 2015). In a direct test of the effect of local example, Theobald et al. (2015) report that during an exercise with an undergraduate biology class, all students gained conceptual understanding with both local and global examples of climate changes. Female students, however, learned more through local examples than global ones; males showed no geographic bias. Just linking climate to an impact on people, however, is not enough. An undergraduate course in climate science through history, for example, increased knowledge of climate change and human interactions as well as interest in the topic, but students were ambivalent about whether the science knowledge they gained was relevant to their lives and current issues (Nam and Ito 2011). Nor did studying the collapse of past civilizations help alter their current environmental behaviors.

Engaging learners

The programs, curricula, and lessons tested in this set of reviewed articles used a variety of engaging, active, and student-centered teaching methods. Whether the intervention was described as using an experiential, inquiry-based, or constructivist approach, these teaching methods have been proven to be effective for science and environmental education (Bybee et al. 2006; Jacobson, McDuff, and Monroe 2015) and are therefore frequently used in climate change education as well. The interventions described in many articles included teaching methods such as debates, small group discussions with worksheets, hands-on labs, and field trips (Alexandar and Poyyamoli 2012; Karpudewan, Roth, and Chandrakesan 2015; Leigh 2009; Lester, Ma, and Lee 2006; Pruneau, Doyon, Langis, et al. 2006; Reinfried, Aeschbacher, and Rottermann 2012; Theobald et al. 2015). In some countries, however, this type of learning may not be commonplace and important research questions have been raised about the effectiveness of different teaching methods. For example, Karpudewan, Roth, and Abdullah (2015) explored the experiential learning process 5E (Bybee et al. 1990) to compare a student-centered process to a traditional teacher-centered approach with 11-year old students in Malaysia. After the 5-week unit, the treatment group's scores were significantly higher on global warming knowledge and environmental attitudes.

One study used a fast-paced, one-hour, assembly format with music and graphics to engage high school students in understanding the risk of climate change and the power they have to make a difference. An evaluation suggested that participants' knowledge of climate science, their engagement in the issue, and all but one behavior (carrying a reusable water bottle) increased significantly after the presentation. Those who were disengaged, doubtful, or dismissive of climate change science before the program were most likely to become more concerned and show increased knowledge of climate science (Flora et al. 2014).

Role-plays and simulations that mimic reality are often used in environmental education materials to involve students in understanding other perspectives, project what might happen in the future, and increase interest and enjoyment in learning. Karpudewan, Roth, and Chandrakesan (2015) used a role-play to help secondary students learn about environmental issues. Dresner (1989) used an energy conservation simulation in undergraduate classes and suggested the simulation of engaging with a community to make a difference contributed to increasing intention to do so in the real world.

Several interventions used some form of visual imagery to capture interest and reach their audiences. In Turkey, pre-service teachers who watched a documentary (*An Inconvenient Truth*) as part of a unit on climate change demonstrated significant learning gains when compared to a control group who did not watch the film (Mutlu and Tokcan 2013). Similarly, an animated educational video shown to 10- and 11-year-old students in India helped increase attention and responses to global warming content (Vethanayagam and Hemalatha 2010). In other cases, simple drawings or cartoons were used to convey information about global warming (Oluk and Özalp 2007; Reinfried, Aeschbacher, and Rottermann 2012).

Other studies focused on providing content about climate change through inquiry-based activities. Similar to the constructivist approach that Karpudewan, Roth, and Abdullah (2015) tested, these activities allowed students to develop their own knowledge and to generate conclusions based on this knowledge (Porter, Weaver, and Raptis 2012). Svihla and Linn (2012) found that using a structured student investigation helped middle school students better understand and integrate the knowledge they gained through interactive visualizations and make decisions regarding energy use. Varma and Linn (2012) suggest that specific directions and instructor guidance can help students effectively experiment to gain a deeper understanding of the content covered in an investigation. McNeal, Libarkin, et al. (2014) reported that online inquiry-based activities not only increased students' conceptual understanding, but also their understanding of how complex systems interact. They also found that learning increases were highest in classes that completed the full set of lab investigations, rather than a portion of the labs.

Small group discussions with worksheets, laboratory investigations, and simulations were also engaging strategies, in part because learners were working together, sharing ideas and observations, and coming to new understandings as a result. Social interaction was present among learners from elementary schools to undergraduate courses, as well as adults in workshops and online programs. For instance, despite the difficulty of finding time for discussion in undergraduate biology classes, Theobald et al. (2015) used a flipped classroom design with a worksheet to guide small group discussion. This helped create active learning, which increased conceptual understanding and pro-environmental attitudes. Worksheet-based, small group discussions were also effectively used with cartoon illustrations (Oluk and Özalp 2007; Reinfried, Aeschbacher, and Rottermann 2012) and in botanical gardens (Sellmann and Bogner 2013b) to increase knowledge.

These teaching strategies engage learners and are commonly used by educators in a variety of contexts. While it is important to not lose sight of what we know constitutes good education as we convey climate science (i.e. the previous two themes), it is also important to recognize that the challenges of climate change suggest that good education is not sufficient; additional strategies are needed when addressing politically nuanced controversy.

Themes specific to controversial topics

Four additional themes of teaching strategies emerged that may help move learners beyond the basics of climate science:

(1) Educators used *deliberative discussion* to help learners better understand their own and others' viewpoints and knowledge about climate change.
(2) Learners were given the opportunity to *interact with scientists and to experience the scientific process* for themselves.
(3) Programs were specifically designed to *uncover and address misconceptions* about climate change.
(4) Learners were engaged in *designing and implementing school or community projects* to address some aspect of climate change.

Deliberative discussion

Discussions and conversations among learners were used to help them think more deeply about concepts, compare perceptions, understand different opinions, and reflect on what they know. Klosterman and Sadler (2010), for example, introduced a three-week unit on climate science to high school chemistry students with a series of exercises involving discussions of students' personal reactions to global warming coverage in the news. Using a 'jigsaw' format, students were then introduced to the positions of five different fictitious organizations with varying interests in climate change. Only after this social context was established did students begin laboratory exercises to explore fundamental concepts of climate science that would help them to assess the positions of the five fictitious organizations. The authors attribute students' increase in understanding of global warming and climate change to their approach to this socio-scientific issue that emphasized personal reflection, group discussion, and clarification of the science content.

In another study, a unit on the greenhouse effect and global warming provided an opportunity for Mason and Santi (1998) to observe fifth graders' group discussions and ensuing changes of conceptions. They hypothesized that the experience of expressing, comparing, and critiquing different ideas through classroom discussion would enable students to alter embedded misconceptions and recognize this change in their own thinking. Many of the students explained that group discussion enabled them to realize the gaps in their understanding and create a more satisfactory mental model. For example, the students dispelled misconceptions about the ozone layer influencing climate change through the course of their own conversation with each other. In other words, through discussion, and with slight nudging from their teacher, students were able to identify how their specific theories about climate change contradicted their own broader framework theories, allowing them to rule out some of their initial ideas. The authors suggest that these results support the hypothesis that '[a]rgumentative practice, stimulated in group discussions, allows students to transform their personal beliefs into reasoned views' (Mason and Santi 1998, 82).

However, Öhman and Öhman's (2013) work with deliberative conversations among 16- and 17-year-old students over a 10-week project on climate change suggests that a group of homogenous students may not reflect the full complement of alternative perceptions or minority views. They observed that their study participants were reluctant to address ideological differences head on when discussing climate change. Instead, they tended to move toward consensus and were less likely to disagree or provide counter-arguments to others' points. While a science teacher would be pleased with students who agree with the scientific consensus on climate change, helping students make sense of the controversy may require that others voice valid concerns about policy debates, economic choices, and the costs and benefits of various mitigation scenarios.

Holthuis et al. (2014) also explored the fundamental nature of the conversations as teachers used new materials about climate change in their middle and high school classrooms, identifying three levels of engagement: (1) Engaged/Interacting refers to students who were engaged in the lesson and in a discussion with another student or a teacher; (2) Engaged/Not Interacting refers to students who were on task, but not talking with others (e.g. listening, reading); (3) Disengaged refers to students who were not on task. Perhaps not surprisingly, engagement with interaction correlated with higher learning gains while disengagement correlated with lower learning gains. In addition, engagement without interaction showed no correlation to learning gains. Thus, Holthuis et al. (2014) suggest that student interaction (rather than just listening intently) is an important factor in learning gains. More specifically, they suggest the importance of 'epistemic' discussions, or 'how do we know talk,' where students practice making a claim and then supporting that claim with evidence.

Similarly, Lambert and Bleicher (2014) developed a graduate level course for environmental education students that focused on preparing educators to communicate scientific claims and critique arguments about climate change. Student journals revealed that the argumentation process was a powerful format and helped them learn more about science and skeptical claims.

Based on the assumption that social norms govern individual behavior, an online game for adults, GREENIFY, used peer pressure to share information, build efficacy, and launch commitment to new behaviors (Lee et al. 2013). Pre- and post-surveys and interviews suggest the experience helped participants learn more about their impact on climate change and felt more empowered to do something. One participant commented that it was the interaction with other players that was most powerful.

In another study with an adult audience, McNeal, Hammerman, et al. (2014) focused on designing safe and open learning environments to engage members of faith, agriculture, school, and recreation communities in climate change conversations to create a productive dialogue and to build relationships among people with diverse viewpoints. Three factors were most important for influencing participants' experience: feeling that their viewpoints were respected, learning new information about climate change, and learning about others' perspectives on the issue, especially faith-based perspectives.

Interaction with science and scientists

Several studies used data and technology to help participants understand the process of climate science. In some cases, students interacted with scientists (Faria et al. 2015; Hallar, McCubbin, and Wright 2011) to collect measurements, share hypotheses, or discuss projects. Evaluations suggest these interactions helped inspire students' interest in science, particularly if students were able to visit a laboratory.

One educational program trained university students to use technology, such as Geographic Information Systems, remote sensing, and satellite data technology to map snow cover and deforestation, to appreciate global change (Cox, Kelly, and Yetter 2014). Pre and post assessments of knowledge of climate change indicated that students' content knowledge increased significantly. Courses that included additional work with remote sensing tools increased student awareness, confidence, and understanding about climate change.

Teams of scientists and educators collaborated on the development of a number of climate change programs, making sure the science was accurately and helpfully conveyed (Gold et al. 2015; Holthuis et al. 2014; Lester, Ma, and Lee 2006; McNeal, Libarkin, et al. 2014). Student learning occurred in a variety of contexts, from online inquiry-based activities (McNeal, Libarkin, et al. 2014) to interpreting and visualizing authentic scientific data from the Arctic (Gold et al. 2015). Building online information and databases into educational materials enabled learners to access data across space and time, creating important opportunities to build understanding (Cox, Kelly, and Yetter 2014; Gold et al. 2015; McNeal, Libarkin et al. 2014). For example, McNeal, Libarkin, et al. 2014 attributed an increase in systems understanding largely to the instructional focus on the concept of scale, allowing students to study changes taking place on multiple temporal and spatial scales, including those that are outside of human perception (e.g. changes that take place over millennia).

Integrating the skills of educators and scientists provided multiple benefits. Teachers involved as collaborators on program development gained confidence in facilitating student exploration about the nature of science. Where they reported struggling, program developers were able to provide additional instructions and figures (Gold et al. 2015). Other authors reported that the use of data (even student-collected data) and discussions about how scientific knowledge is constructed were essential to student learning about the evidence for climate change (Holthuis et al. 2014; Karpudewan, Roth, and Chandrakesan 2015) and how to justify these conclusions to counter skeptical claims (Lambert and Bleicher 2014).

Addressing misconceptions

Several studies focused specifically on overcoming misconceptions regarding climate change. Perhaps the most prevalent misconception addressed in these studies is the conflation of climate change and the ozone hole (Baker, Loxton, and Sherren 2013; Karpudewan, Roth, and Chandrakesan 2015; Mason and Santi 1998). As discussed above, Karpudewan, Roth, and Chandrakesan (2015) and Mason and Santi (1998) report success in dispelling misconceptions through a constructivist approach focused on guided discussion among students.

Conflating climate change with the ozone layer is not restricted to youth. Liu et al. (2015) described on the impacts of a climate change-focused professional development workshop for secondary school science teachers in the United States. Participants attended a weeklong workshop and three one-day follow-up workshops on climate change. The authors reported success in increasing concern regarding climate change and improved understanding of how humans affect climate; however, some participants who expressed concern about climate change continued to see the ozone layer as a significant contributing factor to the problem. Niebert and Gropengiesser (2013) discussed similar confusion in a group of 18-year-old German students. Those authors reported success in changing student perceptions by directly addressing misconceptions with experiments that help leaners visualize and understand faulty lines of reasoning. For example, instructors developed lab experiments designed to illustrate the heat-trapping qualities of carbon dioxide. By considering the results of these experiments, students were able to understand the role of atmospheric carbon dioxide in trapping heat.

Reinfried, Aeschbacher, and Rottermann (2012) describe a similar experiment in which students were asked to hypothesize about the impacts of using air or carbon dioxide to obstruct radiant heat. This case, however, emphasized the importance of how the concepts are conveyed to students. Results showed greater learning gains from materials designed based on Aebli's (1983) criteria for fostering constructivist learning than from more conventional materials. These criteria are (1) start with students' prior knowledge, (2) untangle complex processes into successional steps, (3) reduce the content to focus only on key ideas necessary to learn the new mental model being presented, and (4) avoid technical terms.

School and community projects

Several of the studies focused on elements of the educational intervention that reached beyond the classroom or training to provide learners with an opportunity to conduct a climate change project in the larger context of their school or community. In the United Kingdom, middle and high school students played a key role in reducing their school's energy use by learning about energy resources, collecting data and monitoring energy use in classrooms, and planning and implementing appropriate actions projects within the school. After implementing several no-cost projects, the schools reduced their electrical usage by an average of 35% (Leigh 2009).

In several studies, students engaged in projects that enabled them to communicate climate change concepts to others. In Crete, an energy efficiency education program resulted in students conserving energy at home and sharing information with their parents (Zografakis, Menegaki, and Tsagarakis 2008). In the United States, university faculty developed a climate change course that also taught media literacy and assigned groups to create public service announcements (Rooney-Varga et al. 2014). In an international exchange project, participating high school students met people who had been affected by climate change and worked with them in service projects, both of which influenced the importance they placed on climate change (Stapleton 2015). Upon returning home, some students voluntarily changed their environmental behaviors, took part in a variety of social action projects, and became leaders within their schools and communities as they shared climate change information with others.

In Canada, students combined a research project with community outreach as they conducted research on local climate change and presented information in a video that was sent to schools in their region (Pruneau et al. 2003). The students also planned and implemented action projects, such as planting trees with signage to explain the ecological value of trees. Student interviews revealed that these projects helped change their ideas about climate change and empowered them.

Discussion

Our review of 49 studies that reported results of educational interventions suggests six themes that contribute to effective climate change education. While every paper reported some attribute of their success, few programs employed more than three themes in the strategies they used to engage learners in considering climate change; constraints on each program included learner age, cultural context, and opportunity. The mere practice of these strategies does not guarantee climate change education programs will be effective, but rather, they are likely meaningful ways that any program can be enhanced. Educators can use the themes to inform their choice of curriculum and teaching strategies when addressing climate change.

Every article described educational strategies that illustrated either (1) personal relevance and (2) engaging teaching methods or both. These themes focus on many of the same guidelines that environmental educators and science educators have been espousing for decades. For example, the Guidelines for Excellence in Environmental Education suggest that materials and programs should be learner-centered and allow learners to create their own understandings and develop new skills through active, hands-on, inquiry-based learning opportunities (NAAEE 2004). Within the field of science education, one framework, the Knowledge Integration Framework (Linn and Hsi 2000; Svihla and Linn 2012), suggests that educators: (1) make content accessible by connecting to personally relevant experiences or building on student ideas, (2) help students learn from each other by allowing them to compare ideas and debate viewpoints, (3) make thinking visible by using models, visuals, data collection and analysis, and (4) promote lifelong learning by creating an inquiry process and motivating its use.

Many of the programs captured in this review do this. They include activities that allow learners to actively engage with concepts, discuss their understanding, practice actions, and engage with relevant, local examples of climate change impacts. We wish to reinforce that good education for climate change can include the full complement of teaching methods that are proven to be successful, such as field trips, flipped classrooms, simulations, worksheets, data collection, role plays, and community action projects.

In the context of the first theme – personal relevance – the challenge and goal are similar to those in other educational contexts. Personal relevance is a prerequisite for good education–it enables learners to link what they already know with new material, create interest and meaning, and attend to the information (Kaplan and Kaplan 1982). Some aspects of climate change, such as lack of direct and visible culprits, remoteness of impacts, and time lags between emissions and impacts to the climate system, may challenge educators to make their lessons personally relevant (Dilling and Moser 2007); however, it is clear from this review that these connections are possible and effective. Programs in our review often focused on the projected impacts of climate change to local ecosystems, agriculture, and communities. They connected data from the distant Arctic to local weather patterns (Gold et al. 2015). Some of the programs tackled climate misconceptions by simplifying information, providing relevant examples, and using vivid illustrations (Baker, Loxton, and Sherren 2013; Bofferding and Kloser 2015; Oluk and Özalp 2007; Reinfried, Aeschbacher, and Rottermann 2012) while others did so through constructivist reflection and discussion (Holthuis et al. 2014; Mason and Santi 1998; Niebert and Gropengiesser 2013).

The second theme – engaging students – is also a prerequisite for good education. Educational programs in this review demonstrate strategies for engaging students through small group discussions, debates, laboratory experiments, online chats, and a host of other strategies. However, in the context of this theme, climate change represents an unusual combination of factors. Educators must address not only complex science, but must also consider how social factors, such as group identity, the threats to values posed by solutions, lack of political will, and the media's practice of balancing opposing views, make it challenging to explore climate change and climate solutions (Dilling and Moser 2007; Kahan 2009; Monroe et al. 2015; Wibeck 2014). In short, climate change educators have the challenge of creating an atmosphere that is welcoming to a diversity of perspectives on climate change, while dispelling students' misconceptions about climate science, which are often heavily supported by socio-cultural factors.

Two broad perspectives on learning – both anchored by the theme of engaging students – can help address this challenge. The first, experiential learning, encompasses the process of active engagement and discovery with reflection and mental engagement (Kolb 1984). The second, social-constructivist perspectives, emphasizes that knowledge is constructed through social interaction (Dillon 2003), such that the process of learning occurs through small group discussions, debates, deliberations, and opportunities to contrast perspectives (Powell and Kalina 2009). The challenge of climate change education points to the potential need to combine these perspectives in a new way.

While NAAEE Guidelines for Excellence (2004) call for programming that provides students 'with opportunities to construct their own understandings through hands-on, minds-on investigations' (1) and reflect a 'diversity of perspectives' (5), they are less explicit about the possibility that people can interpret scientific facts differently, have different ideas about what that information means, or choose to ignore facts. Suggested questioning strategies and inquiry approaches are described in the context of exploring the surrounding world rather than understanding how we come to know the world (NAAEE 2017). The challenges of climate change education suggest that the type of education we have always done may not be sufficient to engage learners in the metacognitive chore of understanding how they think and questioning the justification for their ideas. Therefore, the Guidelines for Excellence might be broadened to offer strategies for exploring science-based, yet culturally influenced issues.

Other studies reviewed here illustrate how guiding student investigations and fostering deliberative discussion can improve scientific understanding and expose learners to multiple perspectives (McNeal, Hammerman, et al. 2014) though in some classrooms one perspective dominated (Öhman and Öhman 2013). Through collecting and analyzing data from field studies (Cox, Kelly, and Yetter 2014; Faria et al. 2015; Hallar, McCubbin, and Wright 2011), performing classroom experiments (Niebert and Gropengiesser 2013; Reinfried, Aeschbacher, and Rottermann 2012), and participating in guided discussions (Holthuis et al. 2014; Karpudewan, Roth, and Chandrakesan 2015; Klosterman and Sadler 2010; Lambert and Bleicher 2014; Mason and Santi 1998; McNeal, Hammerman, et al. 2014), students were encouraged to explore their own assumptions and perspectives regarding climate change in the context of sound science and others' perspectives on the issue. The process of explaining what they know with an opportunity to critically think about, defend, and extend their ideas often gave them a better understanding of the science of climate change, the diversity of viewpoints, and greater confidence and clarity about what they know. It also gives learners practice responding to those who hold different perceptions.

The processes of both analyzing data and engaging in deliberative discussions that challenge learners to explain where their ideas come from are also techniques for overcoming misconceptions. While much of the research into scientific misconceptions focuses on concepts that are difficult to see or experience (e.g. the tilt of the Earth or the movement of electrons), perceptions about climate change may also be affected by socio-cultural norms and worldview. Cultural cognition is an acknowledged element of adult perceptions on climate change (Maibach, Roser-Renouf, and Leiserowitz 2009; McCright and Dunlap 2011) but it may affect youth to a lesser degree (Stevenson et al. 2014).

In addition to the challenges described above, climate change educators have the added task of inspiring action. Climate change education assumes that the public has a role to play in mitigating and adapting to climatic changes and in influencing policy and community planning (U.S. Global Change Research Program 2009). It is easy to feel hopeless in the face of global change, reticent leadership, and powerful industries. Yet the programs captured in this review found a number of ways to instill hopefulness and to motivate learners to take action. Some programs matched the problem to a scale that learners could approach. Rather than exploring global change, they looked at community impacts and strategies that communities could use (Bofferding and Kloser 2015; Cone et al. 2012; Lee et al. 2013; Pruneau et al. 2003). First-hand exposure to people who are currently experiencing climate change (Stapleton 2015) and interaction with scientists who study climate change (Hallar, McCubbin, and Wright 2011; Pruneau et al. 2003) appear to help motivate students to learn more and empower them to take actions. For young learners, this often involves communicating information to other audiences (Lester, Ma, and Lee 2006; Pruneau et al. 2003; Rooney-Varga et al. 2014). In addition, several programs linked actions to climate change by conveying the connections that personal behaviors have to carbon emissions or adaptation efforts (Chauhan et al. 2009; Cordero, Todd, and Abellera 2008; Flora et al. 2014; Lee et al. 2013; Leigh 2009; Zografakis, Menegaki, and Tsagarakis 2008).

Future research could further explore how the themes of personal relevance and student engagement relate to the challenges of overcoming misconceptions and inspiring action. As with other social issues, educators may find it helpful to engage learners in discussions that question assumptions, identify values, compare evidence, and explore perceptions (Sadler 2011). Given the strength with which misconceptions were held in many of the studies reviewed here, additional research could explore how to approach misconceptions at various ages, including the role that a metacognitive focus can play in teasing apart socio-cultural reinforcements from basic scientific misconceptions with various audiences and whether nonformal educators can assist with this work, as they typically have less interaction with students than classroom teachers. Are some impacts of climate change more relevant and meaningful to learners of different ages? Will economic impacts resonate more with adults than concern for native plants and animals? Given the importance of hopefulness in the context of climate change (Li and Monroe forthcoming), future research could explore the degree local impacts motivate learners to understand climate science, or if an understanding of climate science is a prerequisite to making sense out of local impacts, or whether parental perceptions of climate change affect student motivation and action taking.

People at every age are sensitive to social norms, and several programs used the development of community-based expectations to support participants' efforts to change behaviors or take action (Flora et al. 2014; Lee et al. 2013; Robelia, Greenhow, and Burton 2011; Stapleton 2015). It would be interesting to explore whether school and community projects that empower learners, build skills, and nurture hope for change (Leigh 2009; Pruneau et al. 2003; Rooney-Varga et al. 2014; Stapleton 2015) also affect one's adherence to social norms and worldviews. Several programs help adults feel comfortable enough to explore value-based positions and interests (Mathews 2014; McNeal, Hammerman, et al. 2014). Additional research might explore whether this process also helps them overcome their group identity and cultural cognition. And finally, a review of research papers cannot begin to articulate the state of climate change education and policy, but additional research could better understand how nations address climate change, the value or cost of a national curriculum that determines how this topic will be presented, gaps in pedagogy, and whether texts and programs seek the lowest level of agreement or shoot for the greatest vision.

Summary

The studies included in this review reported a range of educational program outcomes, including increasing awareness and knowledge of climate change science and potential impacts, both locally and globally. Some of the programs aimed to address more than knowledge and attitudes about climate change. These programs were designed to build skills to assess scientific conclusions, for example, and empower learners to engage in actions to help mitigate or adapt to climate changes. While the latter goal could be outside the bounds of some science education programs, it is well within the definitional goals of environmental education. The UNESCO Climate Change Education for Sustainable Development program, for example, helps audiences 'understand, address, mitigate and adapt to the impacts of climate change, encourage the changes in attitudes and behaviors needed to put our world on a more sustainable development path, and build a new generation of climate change-aware citizens' (UNESCO 2010, 4).

Very few articles in our collection, however, embraced the goal for climate change education articulated by Kagawa and Selby (2010, 4): 'the learning moment can be seized to think about what really and profoundly matters, to collectively envision a better future, and then to become practical visionaries in realizing that future.' In addition, we identified very few educational programs that intentionally approached climate change from both social and science disciplines (multidisciplinary, interdisciplinary, or transdisciplinary). While these programs may exist, our review of the peer-reviewed research literature did not capture them. A review of national educational policies and programs, or one of evaluation reports, may result in a different finding. Perhaps Kagawa and Selby's vision provides the needed direction for which new curriculum should be designed. As climate change education programs grow and build upon the successes of others, they can play an essential role in developing communities of such practical visionaries necessary to address future challenges.

Note

1. Recognizing that literature reviews have the potential to identify, document, and share compelling evidence and research findings about effective environmental education, the North American Association for Environmental Education (NAAEE) embarked on a project to serve the field with their eeWORKS project, and identified climate change education as one topic for study (https://naaee.org/our-work/programs/eeworks). The impetus for this project comes from funders who want to know what is most effective and practitioners who want to put research findings into practice. The eeWORKS project began by synthesizing the literature associated with academic outcomes of environmental education (Ardoin et al. forthcoming) and is currently exploring how environmental education programs address conservation outcomes and the role of environmental education in early childhood. While each project uses similar strategies for a systematic literature review, the search terms and decision rules are different. As part of the eeWORKS project, summaries and suggested strategies for educators will be available on the NAAEE website.

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