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What effective design strategies do rural, underserved students in STEM clubs value while learning about climate change?

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ABSTRACT
This study investigated the experiences of rural, underserved middle school students in afterschool clubs. Culturally relevant climate change education strategies were used to enhance students' climate change literacy. We investigated changes in students' climate change literacy, perceptions of strategies used, and what they valued about the clubs by analyzing a pre-post survey (*N*=97) and structured written reflections (*N*=113). A new integrative framework brought together climate change education design elements to promote culturally relevant programming in an afterschool setting. The effective climate change education strategies and Expectancy-Value Theory (EVT) guided data analyses. Overall, students demonstrated significant growth in climate literacy; beliefs, attitudes, and subjective knowledge did not increase significantly. Students' reflections indicated some climate change strategies resonated more than others. Analyses using EVT found that students' interest/enjoyment and identity were most often described, followed by self-efficacy and expectations for success with club tasks. Implications for practice are shared.

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Rural populations in the southeastern U.S. are disproportionately impacted and more susceptible and vulnerable to the effects of our changing climate, such as sea level rise, hurricanes, heat waves, and drought (Gutierrez and LePrevost 2016). These populations (e.g. people of color, impoverished) are often those whose voices have been silenced from the climate justice conversation (Burnham et al. 2013). Schools can play a vital role in addressing climate change concerns of locally-impacted communities; as students learn more about their local environment, it spurs them to become advocates for their environment (Myers et al. 2013). Taber and Taylor (2009) found that engaging students in interesting hands-on classroom experiences that are culturally relevant and relevant to their own geographic location will stimulate students to develop more accurate content knowledge. Climate change education for youth holds the promise to improve community response to climate change. Youth can serve as environmental ambassadors within their local communities (Duvall and Zint 2007), sharing their climate knowledge with their parents (Lawson et al. 2019) and influencing community members and local leaders (Hartley et al. 2021).

As such, out-of-school time activities can provide an alternative setting to explore climate-related content for American youth, as within-school coverage of climate change is limited in time (Plutzer et al. 2016) and scope (National Center for Science Education 2020). A wide range of afterschool educational opportunities (e.g. robotics clubs, Science Olympiad, STEM Clubs) have become more common within the last decade (Robelen 2011; Vijil and Combs 2015). These voluntary activities are often infused with strong engagement components that both motivate students to attend and garner student interests (Barker, Nugent, and Grandgenett 2014; Eccles and Templeton 2002). These settings also can provide space for students' cultures to be further reflected in the structure of club activities, through personal interactions with climate science content, STEM professionals, and peer communities of learning (Gutierrez 2016; Blanchard et al. 2018). To date, few studies have investigated learning about climate change in afterschool settings such as extracurricular clubs (Monroe et al. 2019), and the vast majority of these studies examined mostly affluent, White participants (e.g. Geiger et al. 2017; Swim et al. 2017).

This study aims to bridge this gap in the literature to learn more about the climate literacy of vulnerable youth, whose experiences have been underrepresented in the literature and who are likely to be disproportionately and negatively impacted by the changing climate. Building on research syntheses, we present a new and integrative climate change education design framework that centers culturally relevant pedagogy in out-of-school settings. The efficacy of an intervention created using the design elements is researched, including how it impacted students' climate literacy and how youth valued different aspects of the intervention.

Climate literacy

The need for a climate literate public to meet the grand challenges posed by climate change has become something of a rallying cry (Leiserowitz et al. 2021). Over a decade ago, several U.S. governmental agencies (e.g. National Oceanic and Atmospheric Administration, National Science Foundation), non-governmental organizations (American Association for the Advancement of Science), scientists, and educators created a framework to define climate literacy. In a broad sense, climate literacy is 'an understanding of your influence on climate and climate's influence on you and society' (USGCRP 2009, 4). In addition, this framework presents specific content knowledge principles that are deemed important for individuals and communities to know and understand about Earth's climate, impacts of climate change, and approaches to mitigation. *The Essential Principles of Climate Science Literacy* are: 1) The sun is the primary source of energy for Earth's climate system; 2) Climate is regulated by complex interactions among components of the Earth system; 3) Life on Earth depends on, is shaped by, and affects climate; 4) Climate varies over space and time through both natural and man-made processes; 5) Our understanding of the climate system is improved through observations, theoretical studies, and modeling; 6) Human activities are impacting the climate system; and 7) Climate change will have consequences for the Earth system and human lives (USGCRP 2009, 9–16). Research indicates that U.S. adults are not climate literate, holding limited knowledge of these climate science principles (e.g. Ballew et al. 2019).

Congruent with the American adult population, U.S. adolescents also exhibit low levels of climate science knowledge. Leiserowitz, Smith, and Marlon (2011) conducted a survey of 517 youth aged 13–17 years; to date, the most recent nationally representative survey to be conducted with U.S. teens. Of those surveyed on their knowledge of climate change science, only 25% would receive a passing grade (an A, B, or C). Research in environmental and science education echoes similar gaps in teens' knowledge. For instance, Shepardson et al. (2011) found that youth hold many misconceptions about climate science, such as confusion between climate and weather. Although not nationally representative, Busch et al. (2019) found that the majority of middle- and high school-aged youth from a sample in the western U.S. correctly identified human causes and effects of climate change. However, deep conceptual knowledge is generally low among middle school (Bodzin et al. 2014) and high school (McNeal, Libarkin, et al. 2014) students. These trends are not unique to students in the United States; youth in the United Kingdom and Australia also hold incomplete or inaccurate knowledge about climate change (Lee et al. 2020). Taken as a whole, today's youth are unlikely to be climate literate, which may impede their ability to mitigate and adapt to climate change.

Conceptual framework for culturally relevant climate change education in extracurricular settings

In order to design and implement best practices for teaching climate change literacy principles to students from culturally diverse groups in an informal learning setting, the authors explicitly considered three bodies of work: 1) effective climate change education strategies (Monroe et al. 2019), 2) culturally relevant pedagogical strategies (Morrison, Robbins, and Rose 2008), and 3) effective strategies for extracurricular programs (Eccles and Templeton 2002).

Effective climate change education (CCE) strategies

Through a systematic literature review of 49 research papers, Monroe and colleagues (2019) identified six evidence-based design elements for effective climate change education programs: 1) Make it personally relevant; 2) Engage learners in active learning; 3) Promote discussion; 4) Provide opportunities to interact with scientists; 5) Target climate science misconceptions; and 6) Design solutions. The first two design elements are not unique to climate change education and are the foundation of effective science (Bybee et al. 2006) and environmental (Jacobson, McDuff, and Monroe 2015) education.

First, programs should communicate climate change in such a way as to make it personally relevant to learners (Monroe et al. 2019). Climate change is often presented to youth as a global phenomenon affecting large-scale natural systems over long periods of time (Busch 2016), which can be difficult for youth to find meaningful. This lack of relevance due to scale, both temporal and spatial, can serve as a barrier to learning and action. Students can learn more if climate change is related to their local setting (Bofferding and Kloser 2015; Theobald et al. 2015). In general, localized effects and current time scales are more likely to encourage action (Gifford 2011). Second, learners should be engaged in active learning through student-centered teaching methods. One such educational, entertainment (or 'edutainment') program that utilized music, engaging graphics, and young presenters was effective for increasing youth knowledge and concern, particularly among those who were disengaged, doubtful, or dismissive of climate change (Flora et al. 2014). Technology-assisted learning such as video (Mutlu and Tokcan 2013) and interactive simulations (Svihla and Linn 2012) also have proved effective at increasing students' climate science knowledge.

Strategies three through six (Monroe et al. 2019) are not specific to climate change education but apply more generally to the teaching of controversial topics. The third design element indicates that programs should support structures during which learners discuss climate change, helping students to understand multiple viewpoints and perspectives. Klosterman and Sadler (2010) found that discussion among peers about the social aspects of climate change was related to high school students' increased understanding of the scientific content. However, discussion can be challenging; Öhman and Öhman (2013) found that older adolescents avoided addressing ideological differences within group discussions. McNeal, Hammerman, et al. (2014) argued that norms must be established for discussions to be productive, so that students feel safe and respected. Fourth, programs should include opportunities to interact with scientists. Research suggests that students working with scientists to collect or analyze data results in learning gains (Gold et al. 2015) and better understanding of the nature of science (Holthuis et al. 2014). Fifth, programs should specifically target common misconceptions about climate science. For instance, Niebert and Gropengiesser (2013) found that utilizing experiments to show the heat-trapping properties of carbon dioxide helped learners create more concrete mental models of the greenhouse effect. In this case, constructivist approaches which build upon students' prior knowledge and reduce the complexity of new information can help students learn (Reinfried, Aeschbacher, and Rottermann 2012). Lastly, learners should be involved in designing local – school or community – solutions to mitigate or adapt to climate change. By focusing on and implementing solutions to climate change, youth feel empowered to take action (Pruneau et al. 2003).

While Monroe and colleagues' (2019) review offers a systematic and evidence-based list of effective climate change education strategies, most of the studies were conducted with White and urban youth. Thus, there is a need for more climate change educational research to take place with youth who are underrepresented in the literature and underserved due to their geographical location, their socioeconomic status, and/or their ethnic and cultural backgrounds.

Culturally relevant pedagogical (CRP) strategies

A climate change intervention may be more impactful if activities are modified to suit the 'needs, preferences, and values of specific racial and ethnic populations' (Durlak and DuPre 2008, 343–344). Ladson-Billings (1994) terms 'pedagogy that empowers students intellectually, socially, emotionally, and politically by using cultural referents to impart knowledge, skills, and attitudes' as Culturally Relevant Pedagogy (CRP) (pp. 17–18). Culturally relevant practices seek to establish inclusion of students, develop student attitudes, enhance students' meaning, and engender competence (Ginsberg 2005; Ladson-Billings 2014).

Research indicates differences in outcomes of climate change educational interventions, correlated to participants' gender and cultural background. In research by Stevenson and colleagues (2014), adolescents of color and female adolescents were more likely to accept anthropogenic global warming as true, as compared to White and male adolescents. Thus, they recommend that ethnicity and gender should also be considered when developing climate literacy interventions. Young, Young, and Ford (2019) assert that culturally relevant activities should foster self-efficacy in students of color, particularly for those who identify as female. They also encourage the development of peer collaboration networks that foster 'communal responsibility for success and failure' where peers learn to depend on one another as a 'community of learners' (p. 11).

Studies have shown that students are often more invested in topics that hold personal relevance to their lives (Maio and Haddock 2007; Palmer 2009; Swarat, Ortony, and Revelle 2012; Young, Young, and Ford 2019). It may be challenging for facilitators (e.g. teachers, coaches, club leaders) to link home, community, and school if there is cultural incongruency between these environments, which is more often the case for students of color (Young, Young, and Ford 2019). Using local examples that demonstrate the impact of climate change, infusion of activities that are personal to students' daily lives, and integration of real-time events may help to increase participant interest and understanding (Lindahl 2007; Scannell and Gifford 2013). The *Training Manual on Gender and Climate Change* also suggests that females may be 'more responsive to technical [climate science] information when it is presented in a social context' (Aguilar et al. 2009, 185).

Discussion of climate justice topics that disproportionately affect vulnerable populations (Gutierrez and LePrevost 2016) may spark student ideas for STEM projects to help communities mitigate or adapt to their changing environments (Hashimoto-Martell, McNeill, and Hoffman 2012). Afterschool STEM clubs often provide additional opportunities for youth, especially youth of color, to access special instruments/tools (e.g. digital probes, virtual simulations, experiments) that they have not been afforded access to in the traditional classroom setting (Barron, Wise, and Martin 2013). These tools can enhance students' learning and motivation (Swarat, Ortony, and Revelle 2012).

With climate change, the authenticity of climate science data can be enhanced by inviting climate scientists in to speak with students to share their research and present climate science information (Hestness et al. 2014). It has been suggested that students of color should gain exposure to individuals (e.g. local scientists, professionals) who look, act, and talk like they do, to help students develop a science identity (Carlone and Johnson 2007) and feel a sense of belonging in STEM fields (Collins 2018). In their work with gifted girls of color, Young and colleagues (2019) stressed that aspirational STEM mentors are essential, especially 'professionals who have backgrounds and experiences similar to those of the girls receiving mentorship' (p. 14). Collins (2018) also described how students' abilities to see how the field of STEM can affect their own community increased its value and interest to them.

Morrison, Robbins, and Rose (2008) synthesized classroom research to develop a set of effective culturally relevant practices. These strategies include: 1) modeling, scaffolding, and clarifying a challenging curriculum; 2) using students' strengths as starting points for instruction; 3) investing and taking personal responsibility for student success; 4) creating and nurturing cooperative environments; 5) holding high behavioral expectations; 6) reshaping the prescribed curriculum; 7) building on students' funds of knowledge; 8) encouraging relationships between schools and communities; 9) encouraging critical literacy; 10) engaging students in social justice work; 11) making explicit power dynamics of mainstream society; and 12) sharing power in the classroom.

Effective strategies for extracurricular (EC) programs

Afterschool STEM clubs can help participants relate to difficult STEM concepts in a more authentic way (Sahin 2013). Research indicates that afterschool STEM programs have three main benefits for participants: (1) increasing interest in STEM, (2) supporting capacity to productively engage in STEM learning activities, and (3) developing value for the goals of STEM (Krishnamurthi, Ballard, and Noam 2014). Participants often gain exposure to stimulating activities, build new friendships, learn new content and skills, experience a sense of belonging, and find out what areas of STEM they are passionate about (Blanchard et al. 2018). Afterschool programs have been found to improve participants' feelings of self-confidence and self-esteem, increase their social skills, improve their work habits, and decrease observed negative behaviors (Durlak and Weissberg 2007; Vandell, Reisner, and Pierce 2007). STEM clubs can help close the opportunity gap for traditionally underserved (e.g. related to race/ethnicity, gender, and/or SES) student groups in STEM that are related to interest and future career goals, and the changes in the self-efficacy, confidence, and behavior choices of the participants (Gottfried and Williams 2013; Hartley 2014). Sahin (2013) found that participants from diverse groups who regularly attend afterschool STEM clubs matriculate more often into post-secondary STEM majors, as compared to the national average.

The less-structured nature of afterschool settings supports the development of students' communication skills (Mahoney, Cairns, and Farmer 2003). Abernathy and Vineyard (2001) found that students communicated more effectively with their peers by sharing their ideas, experiences, and knowledge; afterward, students took ownership of their own learning and developed a stronger sense of belonging. Participation in afterschool STEM clubs that are designed around a supportive, community framework will allow individuals to try out their STEM identities in a safe and encouraging space. Participants will ideally gain exposure to potential STEM careers that they may not have even known existed. Through career explorations, they can try on different STEM career 'hats' and see if any may fit, such as by searching STEM career information sites, watching related video clips, or meeting STEM professionals (Blanchard et al. 2010; Kier and Blanchard 2020).

Through an extensive review of the literature, Eccles and Templeton (2002) outlined contextual features of out-of-school programs intended to develop positive youth development. These features include: 1) developmentally appropriate structure, 2) social support from adults and peers, 3) inclusive social networks and organization, 4) strong and clear social norms, 5) intentional learning experiences, 6) motivational scaffolding, and 7) opportunities to experience mattering and leadership.

Putting it all together: design element themes

In Figure 1, we provide a new and integrated conceptual framework for designing culturally relevant climate change education in informal contexts, built from the three bodies of work described above. The four design element themes for Culturally Relevant Climate Change Education in Extracurricular Settings – *Activity, Social Interactions, Content, and Community* – (in Figure 1) are described below in relation to strategies for effective climate change education (CCE), Culturally Relevant Pedagogy (CRP), and Extracurricular Programs (EC).

Activity

The first design element centers on activity structures, which should be engaging and pluralistic. In consideration of the three bodies of work, this element includes developmentally appropriate structure and scaffolding from the best practices of extracurricular activities. Ideally, effective climate change education strategies are active, engaging, and involve discussion. Culturally Relevant Pedagogy (CRP) promotes students' use of critical and pluralistic perspectives.

Social interactions

The second design element emphasizes social interactions among and between the students as well as with the facilitator or teacher-coach. Strategies for extracurricular activities include social support from peers and educators, and development of social norms and networks. CRP strategies are similar and include sharing power among learners and educators, establishment of cooperative and supportive settings, and setting high behavioral expectations. The effective strategies for climate change education do not emphasize the social aspects of learning.

Content

The third design element promotes challenging and meaningful content in extracurricular settings. Climate Change Education (CCE) strategies suggest that climate change content

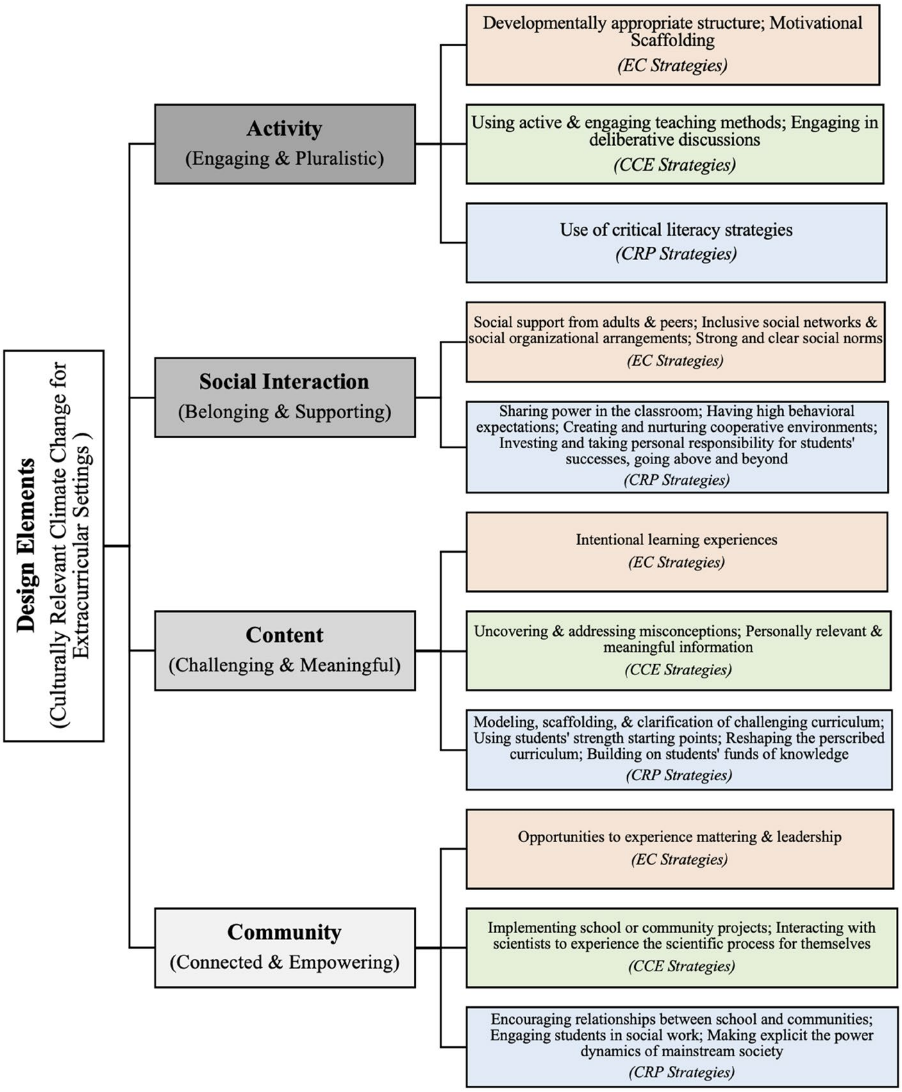

Figure 1. Integrated framework of design elements for culturally relevant climate change education in extracurricular settings.*Note*. EC = Extracurricular (Eccles and Templeton 2002); CCE = Climate Change Education (Monroe et al. 2019); CRP = Culturally Relevant Pedagogy (Morrison, Robbins, and Rose 2008). Design elements (activity, social interaction, content, community) that are more darkly shaded were more often identified as important by STEM Club students.

both addresses misconceptions and is personally relevant to the learners. CRP provides similar suggestions for making content meaningful by starting with students' funds of knowledge.

Community

The last design element highlights the role of the community, which can be development of the community within the club as well as connecting the youth in the club to the outside, larger community. Both CRP and CCE strategies suggest projects and relationship-building between youth and the community. CCE strategies include providing opportunities for youth to interact with scientists, in particular.

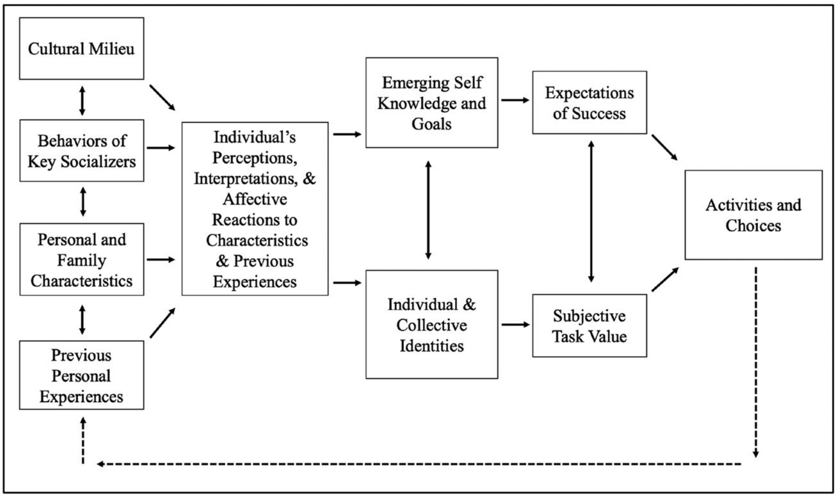

Figure 2. Expectancy-value theory (adapted from Eccles 2009).

Theoretical framework

Expectancy-Value Theory (EVT) of achievement motivation (Eccles 1994) was used to better understand what the students valued from the design elements employed in the intervention. Adolescence is a time when students are wrestling with who they are, what they value, and what they want to do with their lives. Students' experiences and their expectations for their success relate to their personal characteristics, their identity, self-efficacy, and the value or cost they place on their experiences (Eccles 2009; see Figure 2). These values include the importance of the task to the student (attainment value), how useful they find it (utility value), their interest in the task (interest/enjoyment), and how much the task takes of their time and effort (cost) in relation to their expectation of success and their goals (Eccles and Wigfield 1995). Students' values are filtered through their cultural and social experiences, which influence how students see themselves and the choices they make, such as what activities (e.g. homework, hobbies) they choose to persist in. Identities (Eccles 2009) encompass both personal identities, which relate to who a student thinks they are or what makes them feel unique (e.g. *I'm smart, I'm funny*) and collective identities, which ties students to others through their social groups or relationships (e.g. *We have a lot in common*). Therefore, the EVT offers an analytical framework to better understand motivations underlying students' STEM Club experiences.

In summary, the literature over the last decade indicates that most middle school students, ages 11–14, have prior conceptions regarding climate change content knowledge that are alternative to accepted scientific understanding, but that well-designed, culturally relevant interventions can address and improve their climate literacy (Bodzin et al. 2014; McCaffrey and Buhr 2008; Stevenson et al. 2014).

Research questions

Climate change activities were designed for three STEM Club meetings using the design elements for culturally relevant climate change education in extra-curricular settings. The aim of this research was to examine the efficacy, salience, and value of these design elements for these rural students. The research questions are:

1. In what ways, if any, did students' climate literacy change following participation in these intentionally-designed STEM Clubs?

2. In what ways, if any, did students' post-club reflections indicate the salience of the design elements utilized in these STEM Clubs?
3. In what ways, if any, did students' post-club reflections indicate what they valued about the design elements following attendance of these STEM Clubs?

Methods

Research design

A convergent parallel mixed methods research design (Creswell and Clark 2017; DeCuir-Gunby and Schutz 2017) was employed, which involved collection of quantitative and qualitative data separately within the same time span. Data were analyzed separately, and the results were integrated for interpretation. This research design is particularly useful to obtain a more complete understanding of the research problem by triangulating multiple, yet complementary, forms of data (Creswell and Clark 2017).

Context and participants

This study investigated the experiences of adolescents (quantitative data: $n = 97$; qualitative data: $n = 113$), aged 11–14, in afterschool STEM Clubs in four high-need, rural middle schools in the southeastern U.S. The ethnicities (avg.) of the student body of the participating schools were 62% Black, 30% White, 5% Latinx, and < 2% Native American. These school demographics were in stark contrast to the state average of White students (72%). Although individual data is not permitted by U.S. law, most students in these schools (over 98% at three of the four schools) received free and/or reduced-price lunch, which was significantly higher than that of the state (52.8%). As is typical in districts with high levels of poverty (Darling-Hammond 2015), students in the STEM Club schools consistently underperformed students statewide in math and science with an average of 24.7% scoring as proficient in mathematics (state 46.2%) and 57.7% in science (state 72.6%).

Generally, youth who attended the Clubs qualified for free lunch (> 80% of students at all four schools), were people of color, and lived in a rural geographic region that is susceptible and vulnerable to the impacts of climate change. Similar to school demographics, study participants ($n = 97$) were mostly Black ($M = 53.9\%$), followed by White ($M = 24.4\%$). In three of the four Clubs, the percentage of Latinx students (avg. 8.5%) was greater than in their schools overall (avg. 4.6%). Over half ($M = 53.9\%$) of the students were in 5th or 6th grade.

Instructional strategies implemented in STEM clubs

The three climate change-focused Club meetings for this study were part of a larger, federally-funded (3 yr.) project that included 12 afterschool STEM Clubs held over the entire school year, each year. All students in each of the four schools in the southeastern US were invited to participate in the afterschool STEM Clubs. Approximately 70% of the students who regularly attended the STEM Club in year 2 of the grant participated in this study, attending one, two, or three of the climate-change focused club meetings.

The club meetings were designed by the first author, and included strategies identified for effective climate change education (Monroe et al. 2019), culturally relevant pedagogy (Morrison, Robbins, and Rose 2008), and extracurricular settings (Eccles and Templeton 2002). The effective climate change education strategies of Monroe and colleagues (2019) dovetail with many of the culturally relevant pedagogical strategies identified by Morrison and colleagues (2009) and strategies for effective extracurricular instruction by Eccles and Templeton (2002). Thus, the effective strategies for climate change education were utilized as the primary vehicle by which

Table 1. Effective climate change education strategies (Monroe et al. 2019) integrated into climate literacy-focused STEM club meetings.

	Club #1 Weather vs. Climate	Club #2 Greenhouse Gases & Carbon Footprinting	Club #3 Alternative Energies
General Pedagogical Strategies			
Personally relevant and meaningful information	Students wrote personal articles for Club newsletters (v)	Carbon Footprint activity (3,4,6); Gallery walk of their number of earths to show how their energy usage compared to others around the globe (3,4,6); Students wrote personal articles for Club newsletters (v)	Explored types of alternative energy in the region (1,3,6); Students wrote personal articles for Club newsletters (v)
Using active and engaging teaching methods	Collected weather data using novel technologies (5); *Science Girl* video with celebrity host (1,2,3,4,6,7)	Set up carbon dioxide greenhouse to model warming (1,2,5,6); *National Geographic 101: Climate Change & Global Warming* (3,4,6,7); Carbon footprint activity	Alternative energy video clips (1,3,6); Station labs alternative energy (1,3,4,6)
Strategies to teach Controversial Topics such as Climate Change			
Engaging in deliberative discussions	Weather vs. Climate card sort & discussion (2,3,4,7)	Carbon footprint activity on their own lives and around the world (3,4,6); group discussion about the earth being a greenhouse (1,2,5,6)	Station labs with alternative energy snap kits in groups (Solar panel, wind power, kinetic energy) (1,3,6)
Interacting with scientists to experience the scientific process for themselves	Talked to the State Climatologist via Zoom (2,4,5,7); weather data collected (5); climate change over 30 years graph (4,5)	Climate change over 30 years graph (4,5); *National Geographic 101: Climate Change & Global Warming* (3,4,6,7); Guest speakers from WWF, Fisheries PhD student, other scientists (v)	Interpretation of climate change (i.e. graphs) over 30 years (4,5); Energy career options (e.g. featuring scientists, STEM professionals) through video and face-to-face speakers solar panel rep / environmental engineer (v)
Uncovering and addressing misconceptions	Weather & Climate card sort (2,3,4,7); Each newsletter had a quiz & information about climate science (v)	*National Geographic 101* video addressed misconceptions (3,4,6,7); Experiment showing the heat trapping characteristics of carbon dioxide in a greenhouse experiment (1,2,5,6); Each newsletter had a quiz & information about climate science (v)	Energy stations, making a circuit (1,3,6); Each newsletter had a quiz & information about climate science (v)
Implementing school or community projects	Newsletters sent home each week to send links, information, careers (V); Student authored articles appeared in newsletters as well (v)	Make a poster to put around school to reduce impacts (3,6,7); Newsletters sent home each week to send links, information, careers (V); Student authored articles appeared in newsletters as well (v)	Newsletters sent home each week to send links, information, careers (V); Student authored articles appeared in newsletters as well (v)

Note. Climate change literacy principle(s) (1)–(7) that were covered in the specified activity are noted throughout the table; (v) indicates that the principles addressed were varied.

to examine students' perceptions of the salience of the design elements within each of the three climate change-focused STEM Clubs.

Specific culturally relevant pedagogical (CRP) strategies and strategies for implementation in extracurricular (EC) settings were infused with the effective climate change education strategies (CCE) throughout this study. For example, students engaged in deliberative discussions [CCE] in a nurturing and cooperative environment [CRP] through collaborative discussions with peers. These discussions were supported by club facilitators and peers through the development of strong, clear social norms [EC]. Also, activities were created to be personally relevant [CCE], as well as active and engaging [CCE]. Students shared power within their learning community [CRP] by collecting authentic data through active and engaging teaching methods [CCE]. Students also interacted with climate related professionals (face-to-face or virtually) as they broadened their social networks within the STEM community (e.g. state climatologist, solar panel company owner, environmental engineer) [EC]. Efforts were made to introduce activities and guest speakers connected to the youths' local community (e.g. solar farms, measuring and recording local weather conditions) to encourage relationships between school and community [CRP]. Table 1 outlines the club activities, arranged by the effective climate change education strategies shared by Monroe and colleagues (2019).

Club facilitators, or teacher-coaches, participated in a one-day professional development workshop, led by the project team (including authors 1 & 2). Teacher-coaches participated in the Saturday workshop activities as the students would and were provided time and space to plan during and following this workshop at their school sites, prior to each club meeting. This allowed teacher-coaches time to learn content and to prepare for the three upcoming climate-focused club sessions, and also to specifically tailor the lessons to be culturally relevant to meet the needs of their individual student populations (Blanchard, Gutierrez, and Swanson 2021). The teacher-coaches then led their students in the club activities during three club meetings. The project team attended all club meetings at the four middle schools (12 total club meetings), to observe, assist with data collection, and confirm that there was fidelity of implementation of club activities, as outlined in Table 1. This study was approved by the Institutional Review Board for Human Subjects Research at NC State University, Protocol #6177.

Table 2. Survey scales, number of items, response codes.

Scales	# of Items	Response Code
Objective Knowledge: Climate Literacy		
1. The sun is the primary source of energy for Earth's climate system.	2	0 = incorrect 1 = correct
2. Climate is regulated by complex interactions among components of the Earth system.	6	
3. Life on Earth depends on, is shaped by, and affects climate.	1	
4. Climate varies over space and time through both natural and man-made processes.	16	
5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.	2	
6. Human activities are impacting the climate system.	43	
7. Climate change will have consequences for the Earth system and human lives.	6	
Beliefs/Attitudes		
Belief in climate change	1	0 = no 1 = yes
Confidence in belief	1	1 = not at all 2 = somewhat 3 = very 4 = extremely
Understanding of scientific consensus	1	0 = incorrect 1 = correct
Worry	1	1 = not at all 2 = not very 3 = somewhat 4 = very
Subjective Knowledge		
Climate Literacy Principles 2, 6, and 7	5	1 = not at all 2 = not very well 3 = fairly well 4 = very well

Data collection and analysis

Quantitative data

A survey was given both pre- and post-intervention, administered to individuals online through Qualtrics. Students took the pre-survey at the beginning of the first climate change STEM Club and took the post-survey at school during an enrichment/study hall period within a month following the final climate change-focused club meeting. Students completed the surveys within 18 min, on average.

The survey was developed using items selected from the Yale Project on Climate Change Communication's *American Teens' Knowledge of Climate Change* survey (Leiserowitz, Smith, and Marlon 2010, 2011) to assess objective knowledge, attitudes, and subjective knowledge (see Table 2 for overview; see Appendix for full survey used). Face validity of the items on the survey was assessed using expert review by two experts: one specializing in climate change/science education, the other in formal/informal science education (Hardesty and Bearden 2004). The survey was modified to both measure the constructs of interest and to reduce the number of items, reduce the length of the survey, and eliminate overly difficult content items. For example, the items that addressed measures of trust in information sources, policy preference, and behaviors were omitted, as were 15 questions that were not specifically addressed in the climate change intervention (e.g. coral bleaching, ocean acidification, whether or not schools should teach about global warming) and those judged to be too advanced for middle school content level (e.g. amount of CO_2 in ppm in the atmosphere, the gradual/fragile/stable/threshold climate system models, specifically how much the temperature has changed and is expected to change). Reliability of the scales was verified by calculating a Cronbach's alpha value to test for the internal consistency of the survey items (Gliem and Gliem 2003).

Objective knowledge: climate literacy. Objective knowledge was measured via 76 items, grouped to represent the seven *Essential Principles of Climate Science* (USGCRP 2009). Student responses to these items were coded as either correct (1) or incorrect (0). Internal consistency for the knowledge-related questions was measured using Cronbach's alpha and found to be .913 (excellent) for the pre-survey and .885 (good) for the post-survey.

Beliefs/attitudes. The survey included 4 items assessing students' attitudes about climate change: belief that it is happening, confidence in that belief, worry, and their understanding of the scientific consensus. Student responses were coded according to the different response scales seen in Table 2. Cronbach's alpha was not calculated for these items because they were all single items and not reported together.

Subjective knowledge. Students' subjective knowledge – how much someone thinks they know about a topic – about climate principles 2, 6, and 7 was assessed using 5 items. Student responses were coded as not at all (1), not very well (2), well (3), and very well (4). Cronbach's alpha for the subjective knowledge questions on the pre-survey was .796 (good) and for the post-survey was .830 (good).

Sociodemographics. The survey also asked about a student's grade, gender, ethnicity/race, and religion.

Responses to the survey were coded as described in Table 2. For a score of a students' climate literacy objective knowledge, their number of correct responses was calculated as a percent of total items possible. For beliefs/attitudes and subjective knowledge, averages of all students were calculated. Survey data were analyzed to evaluate changes from pre- to post-intervention, using paired t-tests.

Qualitative data

Following each club meeting, all students were invited to complete a three-item reflection questionnaire, in which they examined their perceptions about collaboration and offered their general thoughts: 1) Today my unique contributions were valued by my group members. Please share why.; 2) Today my group members and I have a lot in common with one another. Please share why.; and 3) What else would you like to share about your STEM Club experience? For each of the three-climate change-focused meetings, responses were deductively coded by authors 1 and 2 using a priori codes (Fereday and Muir-Cochrane 2006) based on the six elements of effective climate change education instruction outlined by Monroe and colleagues (2019) (see Table 5) and based on the EVT framework (see Table 6). For example, some general pedagogical strategies were coded into the category of *personally relevant and meaningful information*. Some comments that were coded in this category included students writing about what they could do to help the environment, such as what they could personally do to impact climate change. Another major category was strategies to teach controversial topics (such as climate change). Examples coded under this category included students writing about *engaging in productive* [deliberative] *discussions*, *learning from group members*, and *working together to find answers to problems*. A codebook was co-developed to capture samples of how the students' responses mapped onto the constructs with approximately 25% of the sample; then, students' statements were coded, guided by the codebook, by the first two authors. After independent coding of the rest of the data, all codes were reviewed and differences in interpretation were negotiated until there was 100% agreement (Patton 2002).

Findings

Students' climate literacy (RQ1)

Students' climate literacy, measured using objective knowledge questions related to each of the seven climate literacy principles, increased overall from pre- to post-club intervention (see Table 3). Students' correct responses increased 5.1% from 36.3% to 41.4% ($p < .01$). In particular, students showed statistically-significant growth in their knowledge of principles 1, 2, and 6. The largest growth was related to principle 1 – related to the sun as the primary source of energy for the climate system–in which students showed a 14.7% statistically-significant increase in correct answers ($p < .01$). Students also demonstrated a 4.6% increase ($p < .05$) in correct responses for principle 2 – related to the subcomponents of the Earth's climate system – and

Table 3. Pre and post survey results for objective knowledge, % correct.

Objective Knowledge: Essential Principles for Climate Literacy	Pre (all data) $n = 97$	Post (all data) $n = 97$	Difference (all data) $n = 97$	Difference (top quartile) $n = 24$
1. The sun is the primary source of energy for Earth's climate system.	17.4%	32.1%	14.7%**	39.6%***
2. Climate is regulated by complex interactions among components of the Earth system.	50.2%	54.7%	4.6%*	6.9%
3. Life on Earth depends on, is shaped by, and affects climate.	60.0%	58.9%	−1.1%	25.0%
4. Climate varies over space and time through both natural and man-made processes.	39.0%	41.5%	2.5%	20%***
5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.	23.2%	27.9%	4.7%	27.1%**
6. Human activities are impacting the climate system.	32.5%	37.9%	5.4%***	24.2%***
7. Climate change will have consequences for the Earth system and human lives.	31.8%	37.0%	5.3%	25.7%***
Overall	**36.3%**	**41.4%**	**5.1%****	**17%*****

*$p < .05$, **$p < .01$, ***$p < .001$.

Table 4. Pre and post survey results for beliefs/attitudes and subjective knowledge.

	Pre (all data) $n = 97$	Post (all data) $n = 97$	Pre (top quartile) $n = 24$	Post (top quartile) $n = 24$
Beliefs/Attitudes				
Belief in climate change (range: 0-1)	.87	.92	.71	1
Confidence in belief (range: 1-4)	2.44	2.51	2.26	2.42
Understanding of scientific consensus (range: 0-1)	.59	.5	.65	.52
Worry (range: 1-4)	2.69	2.79	2.29	2.63
Subjective Knowledge				
Climate Literacy Principles 2, 6, and 7 (range: 1-4)	2.85	2.85	2.71	2.89

*p < .05, **p < .01, ***p < .001.

a 5.4% increase (p < .001) in correct responses for principle 6 – related to human factors causing climate change.

No statistically significant differences were seen pre- to post-intervention for students' beliefs/attitudes or for their subjective knowledge (see Table 4). Both prior to and after the intervention, most students (87–92%) believed that climate change was happening. Students reported being *somewhat* to *very confident* that global warming was happening. Students were evenly split on their understanding of the scientific consensus, with 55–59% of students correctly identifying that most scientists agree that humans are causing climate change. They were *not very* to *somewhat* worried about climate change. Lastly, students considered themselves to be *not very well* to *fairly well* informed about climate change causes, effects, and ways to reduce climate change.

Climate change education strategies (RQ2)

Using many of the effective climate change strategies from Monroe et al. (2019) and culturally relevant pedagogical strategies stemming from the work of Morrison, Robbins, and Rose (2008), effective strategies for extracurricular settings, climate change-focused activities were designed and implemented. Students were not made aware of the intentional intervention design strategies; however, the research team was interested in the ways in which the participating students did (or did not) recognize and reflect on the primary strategies for effective climate change education immediately following the three club meetings.

In Table 5, the left column provides specific ways in which the six effective strategies for climate change interventions were operationalized for analysis, while the rest of the columns highlight exemplar quotes coded for each strategy by club meeting. For example, students identified specific 'active and engaging teaching methods' that Monroe and colleagues (2019) outlined, such as working in groups, completing hands-on activities, and use of novel technologies. The students valued working in teams and learning through rich discussion about climate change. During meeting #2, students learned about the impact that increasing carbon dioxide has on raising average global temperatures and they explored their own carbon footprints. One student explained some conflict within the deliberative discussions had in his group, 'The reason why [there was team conflict] was we had some different ideas. We had some we agreed on, but some we didn't'. Additionally, many students acknowledged how much they valued activities that were physically engaging. Following meeting #1's exploration of weather and climate, one student wrote, 'I like my experience because I like to do hands-on activities; my favorite thing was doing a hands-on activity'.

In the post-club reflections, youth most often talked about the use of active and engaging methods of instruction (135 unique instances; 57.5% of students) and ways in which they engaged in deliberative discussion (107 unique instances; 54% of students) in their group work (see Figure 3).

Less often, students reflected on learning about climate change, global warming, or alternative energies, and clarifying misconceptions/alternative conceptions (34 unique instances; 15.9% of students). They would share instances of their learning through the clubs, 'We were

Table 5. Operationalized definitions and exemplar quotes of effective climate change education strategies (Monroe et al. 2019) integrated into STEM club meetings.

Strategies *(Operationalized definitions)*	Club #1 Weather vs. Climate	Club #2 Greenhouse Gases & Carbon Footprinting	Club #3 Alternative Energies
General Pedagogical Strategies			
Personally relevant and meaningful information *(Students discussed how the content or pedagogical approach related to themselves)*	I got to use the things. We asked a lot of questions about ourselves. It teaches you a lot of things.	Today I had an unbelievable lesson on how much I could change to save Earth.	STEM is a good experience for me because it helps me learn more about my environment.
Using active and engaging teaching methods *(Students discussed completing group work, hands-on activities, using novel technologies)*	Because I was the recorder and so I recorded the data that we got. I had a tremendous time, because we worked with cool weather tools and I got to do a lot of stuff with weather I couldn't do anywhere else without paying, so all together I had a fun time.	Because we helped each other. We contribute different things to the group. I love working with teammates to understand a problem and designing to make things work out.	We both worked very hard today and it was fun. Assembling the solar clock was very fun. It's a good thing to work with others.
Strategies to teach Controversial Topics such as Climate Change			
Engaging in deliberative discussions *(Students shared ideas, listened to others' opinions, had same/ different thoughts)*	I agree because my group helped me understand what we had to do better even though I wasn't trying my best. No, because we all have differences. I like STEM career club because I have more time to communicate with my friends and I get to learn more.	We all worked together to find answers to some problems we had. We are all funny and we work good with one another. It was really fun and I think this is the most I've ever interacted.	We mainly listened to each other's ideas. We had many similar ideas and agreed on lots of stuff. I learned from my peers and had a good time.
Interacting with scientists to experience the scientific process for themselves *(Students gathered authentic weather data, STEM Club facilitators were seen as STEM professionals/experts, along with the guest speakers)*	[…] we learned what scientists find out the weather and climate. It was great!	My group and I enjoyed each other. We all love to work. I enjoy having the teachers around and I think they help me alot.	n/a
Uncovering and addressing misconceptions *(Students acknowledged learning new material & how their actions impact the Earth, defining climate-related terms)*	This is a fun way to learn about the greenhouse effect and how it works. […] All STEM club meetings are more than fun, but this was a very good way to learn about how and what the greenhouse effect is.	Because we were all friends and we respected others' ideas. Because we are all friends. I enjoyed finding out about how every day we destroy the Earth.	We all took part & worked together in stations. We agreed with what was going on and thought about energy of the future. I liked the activities we done because we learned about creating circuits and the problems in the world with energy sources.
Implementing school or community projects *(Students acknowledged how they intended to share their experience with parents and other students outside of STEM Club.)*	You can learn alot and show it off to parents and other classes.	n/a	I found this week's STEM very interesting and plan on telling my parents about it.

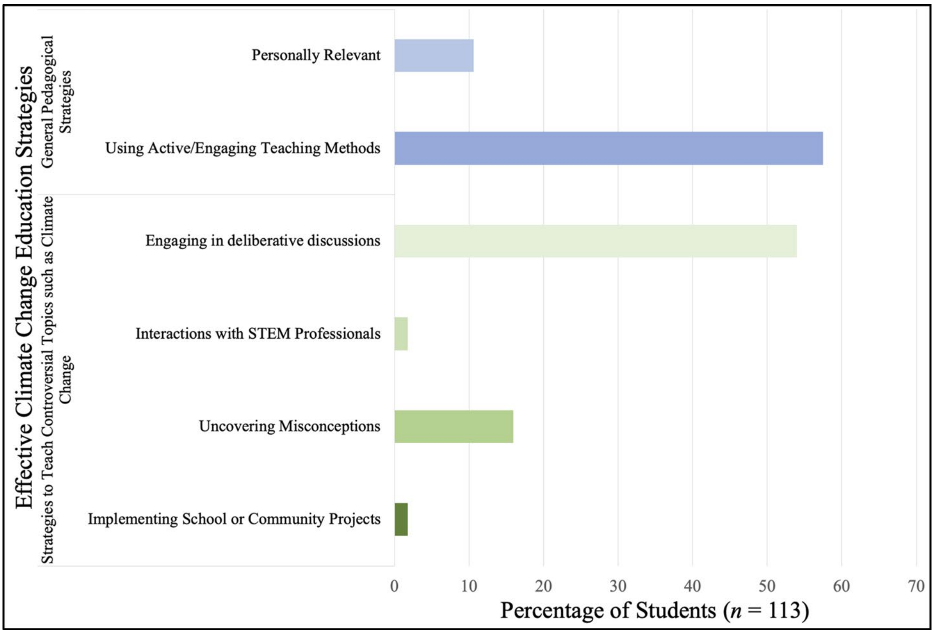

Figure 3. Percentage of students who identified effective climate change education strategies post-club.

able to learn more about the greenhouse and how it affects us', and 'My STEM experience was great because I experienced different ways of climate and weather'. In 19 instances students (10.6% of students) talked of the clubs' relevance to their personal lives, particularly as they examined their own personal contribution, or their family's contribution to Earth's carbon budget, 'Today I had an unbelievable lesson on how much I could change to save the Earth'. Even though students in each club meeting interacted with a live STEM professional (i.e. in person, virtual through teleconferencing software) whose career was explicitly related to the club topic, they wrote about this component even less frequently (9 instances; 1.8% of students).

How students valued STEM club experiences (RQ3)

In students' post-club reflections, they noted several aspects of the club design that contributed to their motivation to attend and participate in club activities. These were coded using the Expectancy-Value motivational framework (EVT; Eccles 1994).

In Table 6, the left column provides specific ways in which seven of the EVT constructs were operationalized to analyze students' reflections, with exemplar student quotes for each meeting. Overwhelmingly, students expressed their interest/enjoyment for the climate change meetings (176 unique instances; 63.7% of students). Students most commonly expressed that they had fun ('fun' was mentioned 115 times) and that they enjoyed the activities ('enjoy-' mentioned 15 times). Interest/enjoyment was coded together (Intrinsic value, EVT) and were most often connected to students' references to active and engaging instructional methods (ECC strategy #2). Students enjoyed the overall design of the clubs, as well as specific, and often novel, science equipment used to explore climate change parameters. One student wrote, 'I had a tremendous time because we worked with cool weather tools and I got to do a lot of stuff with weather I couldn't do anywhere else without paying, so all together I had a fun time'.

Students often identified subjective task values related to the club meetings (e.g. interest/enjoyment, attainment, utility, cost), as well as those for self-schemata and expectation for success (see Figure 4).

Table 6. Students' operationalized definitions and exemplar quotes of expectancy-value theory sub-constructs for STEM club meetings.

Strategies (Operationalized Definitions)	Club #1 Weather vs. Climate	Club #2 Greenhouse Gases & Carbon Footprinting	Club #3 Alternative Energies
Cultural Milieu			
Personal Experiences/Family (Students shared prior experiences or familial relationships of other family members (i.e. cousin, brother)	Yes, everyone had a say so. One was my brother and my best friend. I love STEM.	We are best friends. We understand each other. My parents and family are friends.	I wish that we had Career Club at my old school.
Self-schemata			
Identity/Collective Identity (Students shared individual and group identifying characteristics that aligned with other STEM club students (e.g. smart, kind, nice))	Because we are sometimes funny and silly, we are smart. I would say that climate is a weather pattern of how the weather is over a long period of time.	We worked together very well. We like the same colors and our favorite subjects are science and math. It is a very good club. I learned a lot of things about carbon dioxide.	They treated me like they knew me. We are the same chill, smart, funny.
Expectation for Success			
Self-Efficacy/ Expectation of Success (Students shared their confidences in completing a task and/or helping the team be successful)	Yes, without my contributions the group would not be successful.	Yes, all of my contributions were useful & affectionate. We all have talked with each other & love to laugh. My STEM club experience was very fun & eye opening.	I did stuff to contribute to the group and we had fun with the snap circuits.
Subjective Task Value			
Interest/Enjoyment (Students expressed excitement, joy, satisfaction)	We each had our own job and worked together to complete this experiment. We are all in the same HR and enjoyed this. This was really fun and unique. I enjoyed using the science equipment.	This is a fun way to learn about the greenhouse effect and how it works. I think that most people had fun doing this and I don't know about the other people that were in STEM today but I had FUN! All stem club meetings are more than fun, but this was a very good way to learn about how and what the greenhouse effect is.	We all worked together. We love to play with the circuits, because we like to build and rebuild. It is awesome :) :)
Attainment (Students shared that the club will help them learn and know more about climate and STEM)	I learned about weather and climate also about the tools of weather and climate.	[STEM Club] helps you learn more and helps you know more.	We all worked together. We went well together. We didn't fight or argue. The stations were fun and I learned a lot of new stuff about energy.
Utility (Students acknowledged that STEM Club was useful for understanding content, and being successful in their current school and college)	STEM is a good experience for me because it helps me learn more about science technology engineering and math.	My idea for my group gave us a great experiment. We were all thinking of the same idea. I like stem and I plan on going to NC State.	They made me happy. We all strive for the same goal. It helps me learn more.
Cost (Students noted costs associated with club such as unhealthy team dynamics, the prescriptive nature of following directions, unfamiliarity with the technology used)	They were playing a lot and wouldn't listen.	We worked together even though we don't get along. We had worked together to get it done.	One of my group members were doing all the work and I barely got to do some. One of my group members do not have anything in common but one did. I am going to move around and make new friends.

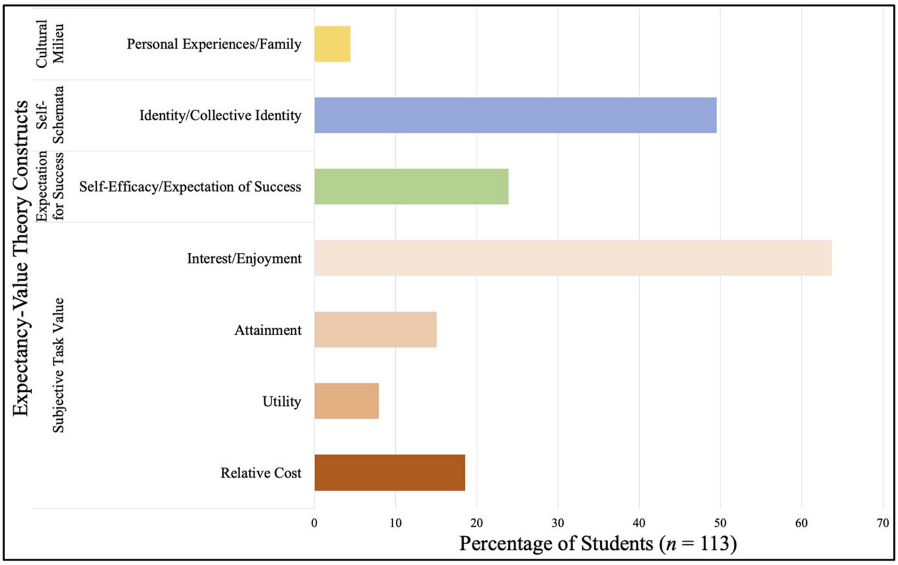

Figure 4. Percentage of students who identified a subset of expectancy-value theory constructs through post-club reflections.

Many students reflected on how the club meetings and their own interactions in the club meetings aligned with how they identified as a person/student (130 unique instances; 49.6% of students), noting their personal characteristics such as intelligence, gender identity, and social skills and confidence, 'We got along very well we worked very hard and together and we tried very hard to get what we have! We are all girls and we are very smart! We have a lot of fun, we share and cooperate!' Many students felt confident in their abilities to complete club activities and work with their partners; students expressed their self-efficacy in 45 unique instances (23.9% of students). Most often the students expressed their self-efficacy in their capability to assist their team in the club activities, 'My ideas helped us do the things we were trying to accomplish'. One student specifically highlighted their confidence in their use of novel technology tools in the clubs, 'I had helped my group by taking care of the data with my knowledge of the technology'. Students also felt as if the content in the climate change-focused clubs, or STEM Clubs in general, would be useful to them (utility was noted in 22 unique instances; 8.0% of students) – 'STEM is a good experience for me because it helps me learn more about my environment'. Students also shared that they felt their participation would help them attain a future goal (31 unique instances; 15.0% of students) – 'We all worked together and finished the assignment.… We were able to work together in peace and get along'. Relative costs were noted throughout student responses as well (48 unique instances; 18.9% of students); students noted disagreements with their group members, had trouble working the technology, or the snack did not meet their standards.

Limitations

Our findings should be viewed in light of several limitations. First, we are unable to rule out all potential alternative explanations for the measured differences in students' climate literacy after the intervention due to the nature of the research design of pre-post versus experimental. Second, the qualitative questions following each of the three club meetings were extremely broad, allowing for variability in response. While this provided space for students to share any and all thoughts about the club meeting and didn't push students into a predetermined response, it also didn't target students to specifically address the club intervention/activity design or their motivation for club attendance. Third, the number of participants in this study was relatively small, and not all of the students in the STEM clubs elected to participate in the research study. The generalizability of our findings, therefore, might be limited to the population of students who participated. Finally, we collected data from these students over approximately a two-month period involving three, 2-hour STEM Club interventions that were focused on climate change. We therefore cannot make any claims about the students' climate literacy or beliefs beyond the period of data collection. With these limitations in mind, we will now discuss the findings of this study in light of the literature.

Discussion

In order to design and implement best practices for teaching climate change literacy principles to students from diverse groups in the informal learning setting, the authors considered three bodies of work for effective design: 1) effective climate change education strategies, 2) culturally relevant pedagogical strategies, and 3) effective strategies for extracurricular programs. In Figure 1 we provided a new conceptual framework for designing culturally relevant climate change education in informal contexts, built from these bodies of work. The four design element themes in the figure (i.e. activity, social interaction, content, community) are arranged in order of importance as identified by the population of students who participated in the climate change STEM Clubs. In the following sections, the design elements will be reconsidered in light of the findings and in terms of how meaningful the elements seemed to be for participating STEM Club students.

Design element: activity

In the clubs, the activity design elements were implemented in each club session through effective climate change education strategies in which students used technologies such as probeware and alternative energy circuit snap-kits. Students also were encouraged to discuss climate change content and work collaboratively in each club session. These aspects were mentioned frequently in student reflections, supporting the findings on peer collaboration and communication skill development by Abernathy and Vineyard (2001) and Mahoney, Cairns, and Farmer (2003). The analysis from the EVT framework suggests that these strategies, particularly those utilizing hands-on and novel technologies, were paramount in motivating students' interest and enjoyment in the club activities. Similar to findings in Stocklmayer, Rennie, and Gilbert (2010), in this study students' professed enjoyment and engagement seem to have been the driving motivation for participants to become involved in informal STEM learning experiences. Students frequently pointed out the engaging activities and discussions as salient components to their STEM Club experiences. Additionally, some students noted that they generally do not have the opportunity to engage in (deliberative) discussions or hands-on activities in their traditional classrooms during the school day. Thus, many of the pedagogical strategies utilized for this informal climate change education environment were novel to students.

The structure of the activities within the afterschool, extracurricular setting were developmentally appropriate for middle school students and included embedded learning scaffolds both throughout each individual club meeting. Climate change content complexity increased throughout the subsequent meetings. However, the non-compulsory nature of the club setting often resulted in inconsistent attendance patterns for students. Therefore, it was essential that the activities were designed so that students could gain any necessary content and skills during a single club meeting. Finally, critical literacy strategies – which are often called for in more formal educational settings and which are highlighted in CRP (Morrison, Robbins, and Rose 2008) – were incorporated in various club activities (e.g. videos outlining global impacts of climate change in vulnerable populations, text describing global utilization of alternative energy) to help students develop skills in comprehension, evaluation, analysis, and reflection. However, students were less likely to acknowledge this skill development in their post-club reflections.

Design element: social interactions

In the clubs, the social interactions design element was exemplified through structures to support successful group tasks and activities. Generally speaking, club facilitators allowed students to self-select roles within groups consisting of 2–4 students, who moved through club tasks. The facilitators were actively engaged with student groups, posing questions and guiding groups as they circulated the room throughout the clubs. Most activities were designed so that groups worked toward a common goal; however, there were some elements of competition embedded within groups in some of the activities (e.g. weather & climate card sorting activity, carbon footprinting activity). Student reflections that centered around collaborative group activities seem to indicate that the STEM Clubs provided a safe space for students to develop a sense of belonging (Abernathy and Vineyard 2001).

In their reflections, the students wrote often about the social aspects of the clubs. In particular, 49.6% of the students made comments associated with the EVT construct of collective identity. Students used 'we' language to articulate how they saw themselves as part of the larger group, reflecting their shared characteristics. Students also discussed their personal contributions to the success of the group; 23.9% of students made comments in their written reflections coded with the EVT construct of self-efficacy. Students recognized the group as a whole and their place within it as being important for the group's success.

One of the subjective task values in the EVT framework, cost, was often (18.9% of students) shared in student reflections. Given students' strong focus on the social aspects of the clubs, it was not surprising that most often the cost for attending the climate change STEM Clubs was associated with social interactions with peers. Students described how they didn't get along with certain named individuals in their group or the larger club, personality conflicts, lack of seriousness ('playing around a lot'), or laziness as their top complaints. Eccles and Templeton (2002) suggest establishing and maintaining strong and clear social norms, while Morrison and colleagues (2008) stress the importance of having high behavioral expectations and establishing a shared power structure for all participants involved in the instruction (e.g. teacher-coaches/facilitators, students). The positive aspects of personal and collective identity in highly social hands-on activities was a more prevalent aspect described by students, likely increasing most students' retention and/or active participation in club activities.

Design element: content

In the creation of the clubs, the climate change science content design element was at the forefront. The three club meetings addressed weather versus climate, greenhouse gases and carbon footprinting, and alternative energy sources. Special attention was given to connecting those science topics to the youths' personal lives, such as examining weather and climate trends of their region, taking weather data at their school, calculation of their personal carbon footprint, exploration of alternative energy sources used within the state, and sharing the climate change content they found personally meaningful in articles they wrote for the club newsletter.

On the whole, international research has shown that youth tend to hold limited amounts of climate change knowledge (Corner et al. 2015) although it increases with age (Lee et al. 2020). Using mostly the same set of survey questions as this study, a nationally-representative sample of U.S. teens indicated that only 25% of youth would earn a passing grade, demonstrating only superficial knowledge of climate change (Leiserowitz, Smith, and Marlon 2011). Furthermore, a deep body of research in science education research has emphasized the numerous and persistent misconceptions that youth hold about climate science (i.e. Choi et al. 2010; McCaffrey and Buhr 2008). The results of this research were consistent with existing literature; we found that climate science content was challenging for these youth. Overall, participating students showed statistically-significant growth in their content knowledge, assessed through the climate literacy principles; yet their mean achievement was still below 50%. It was evident that an increased emphasis on a subset of principles (i.e. principles 4–7) within the club activities design correlated to the largest gains in climate change knowledge. Perhaps the learning goals were too ambitious for three STEM clubs.

Research also indicates that youth do not consider climate change as personally relevant (Gubler, Brügger, and Eyer 2019). In a review of the literature, Lee et al. (2020) found that youth vaguely attribute the causes of climate change to people or pollution, rather than personal behaviors. They identify that climate change will impact temperature but do not trace those changes to impacts on animals, plants, or humans. Lastly, youth suggested solutions that were not personal actions, but rather generic actions such as reducing pollution. In their after-club reflections, only ten percent of the adolescents who participated in the clubs remarked on the relevance of the content to their personal lives. Some students did remark about how the content was meaningful in other ways: 15% of the students described how their new content knowledge would help them to attain a future goal and 8% of the students claimed that the content was useful to them.

While content was a very important consideration for the design of the clubs, results suggest that it was not considered as important or salient to students. The clubs were voluntary, and the students were not required to learn anything at all, so even a modest gain in their climate literacy scores, as measured with a particularly difficult set of items, was welcome. Furthermore, the after-club reflections were completely open-ended, where students could respond to any aspect they wished. The fact that youth mentioned the content at all may be perceived as a positive outcome.

Design element: community

In the clubs, the community design element was infused into club activities regularly, as students were invited to write original articles regarding their learning experiences in the climate change club, some of which were published in their school's STEM Club Newsletter. These school-site specific-newsletters were printed in color and distributed to students at the end of each club, with reminders to show their families, in order to make a connection between the students' school, club, and home/families (Hoyle et al. 2018). This extracurricular strategy was integrated into the clubs to help establish mattering at the individual and family/community level. Even though several students took leadership in authorship roles, which connected personal/STEM Club experiences and climate change content, students did not reference the newsletters in the post-club reflections.

In Club #2 students explored how their individual carbon footprints compared and contrasted to those of the individuals in the larger global community. In their club reflections, students connected the ways in which their personal climate footprinting content was personally and culturally relevant at the individual level and compared to footprints of other children around the world. This activity helped students situate themselves within the larger global climate change crisis (Pink 2018), rather than focusing solely on climate change within their local environments (Bofferding and Kloser 2015; Theobald et al. 2015). Mirroring findings from Pruneau and colleagues (2003), students in the current study reported feeling empowered to make personal changes within their homes, demonstrating their noticing of the extracurricular strategy of mattering as they made plans for climate change mitigation strategies.

Finally, in each meeting, students connected in real time with STEM professionals who represented the students' local, regional, and global communities to learn more about the Club topic of the day. This culturally relevant pedagogical strategy was meant to encourage students to bridge school and community through interactions with local/regional STEM professionals, and to provide space for students to interact and discuss science processes through an effective climate change education strategy. However, the inclusion of live STEM professional guest speakers, even those who closely aligned to students' background and cultures as stressed in the literature (Hestness et al. 2014; Young, Young, and Ford 2019), were not highlighted in the students' responses, even though they were a central component of each club meeting.

Conclusions

In this study, a number of design elements were employed to create culturally relevant climate change education experiences in the context of an afterschool club that served rural middle school students whose backgrounds are historically underrepresented in STEM careers. A number of conclusions can be drawn from the findings in this study. First, middle school students, overall, had significant gains in climate literacy, with most growth focused on the climate literacy principles: (1) the sun is primary source of energy for Earth's climate system, (2) climate is regulated by complex interactions among components of the Earth system, and (6) human activities are impacting the climate system. However, their overall knowledge was still low. The top quartile of students exhibited much greater growth, suggesting differential uptake of the content by students in the Clubs. Second, students' beliefs, attitudes and subjective knowledge did not increase significantly, although students' initial beliefs about whether climate change was happening were very high, and students were *somewhat* to *very confident* that global warming was happening.

Third, students were most likely to positively describe climate change strategies in their reflections that were active and engaging (#2), engaging in deliberative discussions (#3), and uncovering misconceptions (#5) (Monroe et al. 2019). Students were much less likely to describe their learning, its relevance to their lives or the lives of their families, or interactions with STEM professionals. It is unclear the extent to which the efforts to connect with students' lives through interactions with STEM professionals or distributed personalized newsletters were valued by the students or their families, or if these newsletters led to a deeper cultural concurrency between school and home for underrepresented students of color (Young, Young, and Ford 2019). Fourth, the majority of students valued the club meetings, expressing interest and enjoyment of the activities and their use of novel equipment. Students strongly identified with their team members and noted their contributions to those teams through their intelligence, gender identity, and abilities, and also expressed their ability to help their team members. Relative costs, including disagreements with team members, issues with the technology, and the snacks were mentioned by fewer than a fourth of the students.

Implications

In consideration of these findings, we see several implications for the design and implementation of culturally relevant and effective afterschool programs focused on climate change.

1. Students in afterschool clubs can learn climate change literacy principles through short periods of self-contained, non-compulsory instruction in informal club settings.
2. Strategies that provide higher leverage for students should be included first, and then add other additional strategies.
3. Informal learning settings where students are enjoying the experience with peers could lead to more self-directed or in-school learning.
4. It is important for informal learning environments to distinguish themselves as different from school, if that leads to more learning in collaborative groups and more active engagement.

5. Focusing on only 1–2 climate change literacy principles per club, with review in following meetings, could enhance the breadth and depth of understanding.
6. It may be necessary to engage with STEM professionals in more contextualized ways (e.g. labs, field, offices, etc.) to enhance the value of the interaction to the students.

STEM Clubs are free-choice learning. The fact that students increased their climate change literacy and that they talked about how engaging and relevant their experiences were suggests the potential of designing an extracurricular intervention using design elements for culturally relevant climate change extracurricular settings: what is known about effective extracurricular education strategies, culturally relevant strategies, and effective climate change education strategies. The learning and reflections of these students has helped to elucidate which design elements they most valued and what should be considered as climate change educators design and facilitate activities in (in)formal learning environments. What effective design strategies do rural, underserved students in STEM clubs value while learning about climate change? Primarily those strategies that are active and engaging, and that involve supportive, social interaction with peers.

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