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Engaging Middle School Students in Classroom Deliberation and Vertical Farming for Collective Climate Adaptation

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Abstract: Amid the intensifying climate and ecological crises, youth are experiencing heightened anxiety and hopelessness about the future. Freire emphasized the need for action alongside hope, while Bandura highlighted self-efficacy as a key predictor for meaningful action, nurtured through verbal persuasion, direct experience, emotional arousal, and vicarious experience. This mixed-methods study examines how 23 middle school students' understanding of the complexity of the climate and ecological crises evolved through solutions-oriented deliberations on algal blooms in the Great Lakes and engagement in a vertical farming project. Surveys, concept maps, and interviews reveal that factual knowledge alone does not predict deep understanding or action. Similarly, an isolated, one-off experience was insufficient to support sustained systems thinking. Instead, students demonstrated stronger connections between ecological processes, human activity, and potential solutions when learning was iterative, collaborative, and grounded in tangible action. Educators are encouraged to integrate frequent, hands-on, systems-based activities to equip students with the skills and knowledge needed to address climate change.

Keywords: Classroom deliberation; Climate change education; Climate efficacy; Environmental sustainability education; Participative decision making; Vertical farming
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Introduction

Extreme flooding, raging wildfires, prolonged drought, and intensifying hurricanes are some of the effects of climate change that are making the headlines today. These are symptoms of a crisis that will almost certainly pose the greatest challenge to the youth of today, regardless of where they call home. Many young people are beginning to understand the urgency of this global threat and are expressing a desire to be involved in finding a way forward. Canadian youth, for example, are becoming increasingly aware of the urgent need for action and are expressing a desire to engage with quality climate change education (CCE) while at school (Galway & Field, 2023). Joining these youth are educators who wish to provide opportunities for quality CCE in their classrooms, yet who feel ill-equipped to do so (Schwartzberg et al., 2022). With the increasing sense of urgency surrounding climate action, the need for effective CCE is undeniable. Equipping young people with the knowledge and skills to navigate this complex landscape is essential not only for their own futures but for the health of the planet (Karsgaard & Shultz, 2022). When we consider which approaches are most effective, the literature presents a fork in the road. A literature review completed by Monroe at al. (2019) has classified studies focused on describing approaches to CCE into four categories: those that engage learners in deliberative discussion, those that offer learners opportunities to interact with scientists, those that address misconceptions regarding the climate crisis, and those that engage students directly in school and community projects. The present study explores three of these categories by involving students in deliberative discussion around the challenge of algal blooms, addressing misconceptions, and involving them directly in a classroom vertical farming project. The following research questions drive this investigation: 1) How does democratic deliberation impact students' understandings of climate change and adaptation strategies? 2)

What is the impact of a hands-on experience focused on an example of climate adaptation on students' sense of climate efficacy?

This work is grounded in two primary bodies of literature: a) strategies designed to support the development of efficacy in youth, and b) the theoretical reasoning behind these strategies. I focus on the interplay between climate mitigation and adaptation strategies. While both are crucial, climate adaptation strategies are comparatively sparse in educational contexts (Graulich et al., 2021). Focusing exclusively on mitigation may perpetuate feelings of helplessness, as many common examples of mitigation are perceived as having limited impact and rarely produce immediately observable outcomes. Rather, exposing students to tangible examples of climate adaptation could support the cultivation of agency and hope while offering them opportunities to engage with collective responses to climate-related challenges (Ojala et al., 2021).

Despite a range of recommended approaches to quality CCE, it is widely agreed upon that CCE should focus primarily on engaging students in climate change behavior (Busch et al., 2019), which can occur at both individual and collective levels. Doing so positions students as citizens engaged in climate mitigation and adaptation. Recommended approaches to CCE have been categorized into approaches to increase knowledge about the scientific dimension of climate change, to promote engagement or intention to engage in climate change action, and education to access the emotional dimensions of climate change (Busch et al., 2019). Many of these approaches are rooted in what has previously been recommended for quality environmental education (Monroe et al., 2019). The present study focuses on educational approaches to promote climate change behaviors among students.

Bridging the Knowledge – Action Gap

Although climate change is most frequently addressed through the sciences (Monroe et al., 2019), traditional science pedagogy (e.g. prescriptive laboratory experiments and teacher-led lectures) is not promising in terms of engaging students in collective climate action. Reflecting on the goals of science curricula is an important first step in considering the need for alternative approaches to CCE. For example, the three goals for students outlined in Ontario's science curriculum document (Ontario Ministry of Education, 2022b) are as follows:

1. to develop the skills and make the connections needed for scientific and technological investigation;

2. to relate science and technology to our changing world, including society, the economy, and the environment;

3. to explore and understand science and technology concepts.

These in essence focus on scientific literacy, which is common in science education across a larger scale (Busch et al. 2019; DeBoer, 2000), and do not align with the conditions necessary for the cultivation of efficacy described by Bandura (1977): vicarious experience, performance accomplishment, emotional response, and verbal persuasion. I referred to the literature on the emotional dimension of climate change to inform the intervention I used with students. It has been suggested that many youths are experiencing an array of negative emotions in response to the climate crisis (Galway & Field, 2023). For example, 69% of Canadian youth feel let down by the federal government in terms of climate action, and they feel that there is more that their educational system can be doing to in terms of climate change education, however 71% feel that together, we can take action on climate change and make a difference (Galway & Field, 2023). Pihkala (2022 & 2020) describes a vast spectrum of climate emotions and suggests that providing youth with the opportunity to engage in action is in essence an antidote to these negative emotions such as anxiety and despair. Furthermore, the developmental level of middle school and secondary school students is such that they require opportunities to exercise agency in their everyday lives (Patall et al., 2019). Finally, providing students with the opportunity to engage in climate action cultivates efficacy, which supports Bandura's (1977) claim that efficacy is an important predictor engagement in target behaviors. At the same time, educators must help students recognize that meaningful socio-ecological change is rarely immediately observable, supporting them to persist in the face of setbacks rather than equating efficacy solely with successful outcomes (Jensen & Schnack, 1997).

Much of what has been described in the literature regarding the approaches that educators take to CCE involves coverage of climate change mitigation and individual action, and little coverage on adaptation strategies and collective action (Borgerding et al., 2024). As the literature suggests, effective climate change education (CCE) should be seen as a tool for societal transformation (Waldron, 2016; Jickling, 2013). Spending time teaching about climate change as a controversial topic, or through an economic lens is not seen to be quality CCE, in that it does not promote the transformative change that is needed for all of society to move forward. Waldron (2016) proposes that CCE provides students with many opportunities to reflect on their learning and engage them in examples of collective action as opposed to focusing on individual actions and mitigation. Collective action involves many people with similar values coming together to enact change (Grain, 2022).

Providing students with opportunities to explore, design, and participate in climate mitigation and adaptation initiatives is crucial (Ratinen, 2021). Mitigation describes efforts to lessen the impacts of climate change by reducing the levels of greenhouse gases (GHG's) entering the atmosphere, and adaptation refers to strategies to adjust to a changing climate and its impacts. The majority of CCE thus far has focused on mitigation strategies (Graulich et al., 2021). There are many frequently used examples of individual mitigative measures, such as choosing modes of transportation that do not burn fossil fuels, composting at home, investing in solar panels, etc. While these are important actions to take, we know that placing responsibility on individuals to make these choices can be burdensome and is not as impactful as collective action. Collective climate actions might include students working together on a schoolyard greening project, advocating for changes to school or municipal environmental policies, organizing a tree-planting initiative, or collaborating with local organizations to address environmental challenges. Focusing on mitigation can at times perpetuate a despairing mindset, for example when we consider how many people would need to invest in solar panels to even make a dent in our cumulative GHG emissions. Collective action has been offered as an antidote to the burnout that can result from the pressures of individual action (Pihkala, 2020). While ultimately eliminating GHG emissions is a worthy endeavor, the need for adaptation to a changing climate is inevitable. Involving youth in examples of climate adaptation has the potential to be highly engaging for them, in that it offers the opportunity to engage directly with several community-based projects and to consider creative and innovative adaptation strategies (Kwauk & Winthrop, 2021). It can also provide more immediate results relative to climate mitigation, allowing students to see the outcomes of their efforts. This engages students in the engineering design process, a highly valuable experience for them and for our planet, given that we are still in need of ideas that will support climate adaptation that is effective on a large scale.

By examining both some specific strategies for cultivating climate efficacy, this study seeks to bridge the critical gap in climate change education that often overlooks adaptation strategies and collective action.

Methods

The current study is conducted through a socio-constructivist lens. As described in Busch et al., 2018, I subscribe to the socio-constructivist idea that peoples' understandings of and attitudes toward climate change are shaped through social interaction and influenced by the life experiences, value systems, and emotional dispositions that emerge within particular cultural, educational, familial, and community contexts.

Furthermore, Bandura's self-efficacy theory (1977) drives the methodological approach to this work. In a classroom setting, self-efficacy can be cultivated in a variety of ways, by involving students in experiences in which they could see how their actions can be successful, showing them examples of others to whom they can relate acting on issues that are important to them, etc. It has previously been suggested that climate change education within and beyond formal school settings should strive to support the development of self-efficacy in students, as this seems to be the best measure of the likelihood that they will engage in behaviors that fight climate change (Busch et al. 2019; Muroi & Bertone, 2019).

In the current project, I used two approaches: democratic deliberation, and direct experience to prompt performance accomplishments, emotional response, and verbal persuasion. Democratic deliberation is a way of engaging students in dialogue about a challenge that is relevant to them and then engaging them in discussion around possible solutions to this problem (McAvoy & Hess, 2013). This approach positions everyone, including the educator, as a co-learner, and provides all students with an opportunity to share their ideas and to constructively challenge those of others. Engaging students in this way provides them with the opportunity to think critically about topics related to climate change, and to develop informed opinions on these topics. In this study, the students and I used democratic deliberation to explore vertical farming as a possible climate change adaptation strategy in our community. The direct experience involved working with BBC micro: Bits to design a vertical farming system in their classroom. Coding these systems and managing challenges that arose presented many barriers for students to overcome, which prompted emotional response and performance accomplishments as outlined by Bandura (1977).

Participants and Materials

The participants in this study were a group of Grade 7 students (n = 23) at a public school in Ontario, which hosts students living in rural and urban settings. This group of participants was chosen because they represent a mixed demographic in terms of gender, socio-economic status, reflective of the broader population within the region. Additionally, the school was selected for its diverse student body, which includes a range of academic abilities, cultural backgrounds, and varying levels of access to environmental and climate education. This diversity allowed for a more comprehensive examination of the research topic and ensured the findings could be generalized to similar educational settings.

All students enrolled in the participating class were invited to participate in the study. Participation was voluntary and required informed parental/guardian consent as well as student assent. Of the 25 students invited, 23 consented to participate and were included in the study. Participants were selected through convenience sampling based on existing partnerships with the school and teacher, as well as the school's willingness to participate in the study. While the findings are not intended to be statistically generalizable, the diversity of the student population may support the transferability of findings to similar middle-school CCE contexts.

Researcher Positionality

As the researcher, I facilitated and documented the learning experiences examined in this study. I visited the participating Grade 7 classroom three times per week over a five-week period, spending approximately one hour in the classroom during each visit. Throughout the study, I facilitated deliberation sessions, curated learning resources between sessions in response to students' questions and emerging ideas, conducted interviews, and collected observational data. While I was not the classroom teacher, I was familiar to many of the students, having previously taught at the school two years prior to the study. This prior relationship may have contributed to students' comfort in sharing their perspectives and participating in discussions. I remained mindful of the potential influence of my role as both facilitator and researcher on participants' responses and interactions.

Consistent with the socio-constructivist orientation of this study, I recognize that knowledge was co-constructed through my interactions with participants and that my interpretations were shaped by my experiences as a former teacher and environmental educator. To support reflexivity and transparency throughout the research process, I maintained detailed field notes documenting observations, emerging interpretations, and reflections on my role within the study.

Data Collection

Prior to engaging with participants, they completed anonymous surveys which sought to assess their knowledge of climate change. Most questions were taken from a report published by Learning for a Sustainable Future titled Canadians' Perspectives on Climate Change and Education (Schwartzberg et al., 2022). Survey questions were divided into two categories: questions assessing participants' knowledge of climate change, and questions assessing their attitudes toward climate change. These surveys were repeated at the end of the project as well, to allow for comparison of participants' knowledge before and after engaging in the experiences associated with this project.

After the completion of pre-participation surveys, students worked in groups of three to complete concept maps, in which they were asked to include everything they knew about climate change in terms of its causes, effects, and solutions. Concept maps have previously been shown to be effective ways of asking learners to demonstrate their knowledge of a particular topic in of the interconnections between topics (Semilarski et al., 2020) are useful as formative assessment tools for helping educators to curate learning experiences according to the needs of a group (Dhindsa et al., 2011).

Deliberation sessions involved everyone sitting in a circular formation and discussing the challenge of algal blooms in the Great Lakes. Circular seating was chosen because it supports dialogue and reduces hierarchical participation, while encouraging listening and the co-construction of knowledge This aligns with recommended approaches to CCE which place emphasis on perspective sharing, democratic participation, and collective problem-solving (Kwauk & Casey, 2022). Each session was built on the previous session and focused on possible solutions to algal blooms while addressing the potential impacts of these solutions within other components of the social, environmental, and economic systems. At the end of each session, students were provided with materials to support learning about challenging topics that were presented, to inform the content and direction of the following session. During each session, I kept detailed notes on my observations of what connections students were making to learning content, and how this evolved throughout the sessions. I also made notes on misconceptions and ensured that students were given access to material that would accurately address these, so that I was not the one correcting these.

At the end of deliberation sessions, it was agreed that vertical farming would be a solution worth exploring. Participants worked in groups of three to program micro: Bits to operate water pumps and soil moisture sensors. micro: Bits are small programmable microcontrollers containing buttons and LEDs, sensors, and input/output pins that allow students to connect these to and control external devices. In addition to supporting this vertical farming project, using micro: Bits provided students with the opportunity to develop skills in coding and computational thinking, both of which are included in Ontario's Science curricula. Students were shown how to use coding to specify at what moisture levels the water pump would be activated, and how much water would be added each time it was activated. Students then planted lettuce seeds in small pots and placed these under LED lights along with their micro: Bits, water pumps, and moisture sensors. These were then left for two weeks, during which their lettuce began to grow. We chose to grow lettuce because of its short growth period compared to other crops, which suited the short window that was allotted for this study.

Data Analysis

Analysis of pre- and post- participation surveys

Survey questions were separated into two categories: knowledge of climate change and attitudes toward it (Schwartzberg et al., 2022). To compare the results of questions related to climate change knowledge in pre- and post-participation surveys, a Mann-Whitney U test was used. This non-parametric test was chosen due to the small sample size ($n < 30$) of the group of participants. Pre- and post- participation responses to questions were converted into percentages of participants who fit into the various response categories, and these were compared and then analyzed thematically. Although the pre- and post-participation surveys were administered to the same class, surveys were completed anonymously, and individual responses could not be matched across time points. As a result, the pre- and post-survey data were treated as independent samples for statistical analysis.

Analysis of Concept Maps and Interview Transcripts

Inductive (data-driven) thematic analysis was used to highlight themes within these sets of qualitative data. I followed the framework described by Braun & Clarke (2022), which highlights six main steps to be followed: 1) familiarization with the data; 2) generating initial codes; 3) locating themes among the codes; 4) reviewing and revising the themes; 5) deciding on final themes; and 6) writing the final report. Because I was working with three sets of data, this required much cross-referencing between interview transcripts, concept maps, and survey responses. Interview transcripts provided context that was necessary to understand the concept maps and surveys since they primarily consisted of single words and lacked explanation.

Results

Statistical analysis of the climate change knowledge surveys, and thematic analysis of the climate change effects and actions surveys, concept maps, and interview transcripts, revealed four major themes which address the research questions driving this study: 1) knowledge barriers to effective climate action; 2) the importance of relational understanding; 3) The importance of direct and vicarious experience; and 4) the overpromise of technology as a solution to CC.

Misconceptions Regarding Effective Climate Action

At the beginning of the project, concept maps primarily mentioned "pollution" and "gas" as being the culprits of the climate crisis. Concept maps and interviews at the end of the project demonstrated that participants were developing the ability to tease these terms apart by beginning to apply new vocabulary addressed throughout this unit. Although not used with consistent accuracy, its more frequent use was notable. The following terms were used by multiple participants in the interviews and post-participation concept maps: carbon, carbon dioxide, oxygen, fossil fuels, algal blooms, and atmosphere. Sometimes used accurately, there were still some persistent misconceptions that emerged:

> (Climate change is caused by) carbon dioxide, like building up in the atmosphere and being able to get let out. (Alex, 11)
>
> In another exchange, I asked: Why should we care that we had to cut down 500 trees for a field?
>
> To which Skylar, 11 responded: Because it (trees) filters the oxygen that we breathe, and (we want trees to absorb carbon) so that we can have cleaner air to breathe in.

Here, carbon dioxide is villainized, which prompted me to consider whether students were associating carbon dioxide with air pollution that has been a frequent term used since students generated the pre-participation concept maps.

There were points when students seemed to blend different concepts together:

> Because since there's so much pollution building up, and it's getting trapped and not being released, it makes the earth warmer. (Riley, 11)

The idea of something being trapped in the atmosphere being the cause of climate change is quite interesting. There were several times that the basic mechanism of global warming was reviewed with students during deliberations, and the idea of something being "trapped" seems to be the primary concept that was retained. Some students articulated that pollution is being trapped, sunlight, gas, and carbon dioxide. Regardless, it seems to be widely agreed upon that whatever is trapped needs to be let out.

This is what happened when I provided the same prompts to a different group of students:

> They (trees) absorb carbon, which is the stuff that's blocking the heat from going back out into space. (Amara, 11)

Although not wrong, there is this very one-sided view of carbon as the villain. This is a cautionary misconception. Global warming is indeed the result of a build of up heat in the atmosphere, due to the increase in atmospheric greenhouse gases linked directly to human activity. However, the varied explanations of what is being trapped indicate limited comprehension of the complexity of this concept, and an emphasis on linear cause-and-effect thinking. This offers an opportunity for educators to clarify the mechanism of global warming by debunking its perceived connection to a thinning ozone layer and strengthening students' understanding of the different greenhouse gases and their immediate connections to specific human activities.

Somewhere along the way, some students misunderstood sunlight as a limited resource. There is this understanding of the earth having too much of something, that something being trapped, and the need to eliminate it. That "something" varied among student responses. This apparent need to label a culprit or a villain was at times connected to some common misconceptions regarding the climate crisis. For example, this was not the first time that a student has confidently told me that climate change is because the "hole" in the ozone layer is allowing too much of the Sun's light to penetrate our atmosphere, thus causing the warming effect associated with climate change. When asked where they learned this, they replied that one of their previous teachers had taught this to them. A number of other students in the class echoed similar replies to this question. A similar misconception has been documented several times in the literature (Boyes et al., 1995; Daskolia et al., 2006; Dove, 1996; Groves & Pugh, 1999, 2002; Khalid, 2001; Papadimitriou, 2004), and recently, it is a misconception that has come up in my teaching with pre-service teacher candidates.

> I learned the ozone layer's kind of thinning and stuff. And I didn't know what algal blooms were. And I didn't know that there was underground water. (Quinn, 11)

> When you have like actual farms, it's like you use the Sun to grow plants. And like, you also use lots of farm tools, which use gas and lots of CO_2. (Rafael, 11)

Here, it's almost as if Rafael has lumped the Sun in with some of the other costs of large-scale agriculture that were discussed. The implication here is that if we somehow limit the sunlight that we require for food production, this might somehow limit the sunlight that gets through the so-called hole in the ozone layer.

A Mann-Whitney U test was performed to compare climate change knowledge in this group of participants before and after participating in learning topics associated with the topic of climate change adaptation and vertical farming. There was a significant difference in climate change knowledge between the participants before and after participation; $z = -4.68$, $p < 0.00001$.

During interviews, despite still lacking a deeper understanding of the complexity of the climate crisis, students expressed a growing understanding of the level of urgency of the crisis.

> I didn't really know or care about climate change before this project. And now I know that it's terrible. And yeah, we just don't want that happening. We need to figure out something to just like reduce it. Or like, we don't know what will happen to our planet. (Diego, 11)

> I get now that it's (climate change) not just like a little thing that's going on. (Amara, 11)

> I felt like, before I felt not as much into it. Like, I didn't think it was horrible. I didn't think the world was going to, like, end. It's not, but, like, I didn't think it was that bad. But now that I feel, like, now that I've seen, like, all that stuff that's going in, I feel like it's worse than people actually think it is. And that's because it is really affecting our earth. And if we don't do something about it, it's going to affect us later in our lives. (Jaimee, 11)

Despite several of the participants sharing the increased sense of urgency they felt regarding the need for climate action, post-participation surveys show a decline in urgency. For example, when given the prompt "we are experiencing a climate emergency", 20% and 47% of students strongly agreed or agreed with this statement respectively in pre-participation surveys, whereas 0% and 30% strongly agreed and disagreed respectively in post-participation surveys. Similar trends can be observed in fig. 1, panel b. In the post-participation surveys, the number of students who strongly agreed that climate change is happening had dropped by 41%, and students who strongly agreed that climate change is a risk to Canadians had dropped from 38% to 9% (fig. 1, panels a & c). The percentage of students who disagreed or strongly disagreed that their worries about climate change are affecting their daily life had increased from 43% to 61% (fig. 1, panel d).

The Importance of Relational Understanding

By the end of this unit, many had begun to use terms such as fossil fuels and carbon dioxide, and all participants correctly identified the maximum viable level of warming (1.5°C) in the survey. However, post-participation concept maps and interview responses revealed a limited understanding of the relationships between these terms. For instance, students were unable to explain the link between fossil fuels and carbon dioxide, and many struggled to associate the human need for energy with the use of fossil fuels.

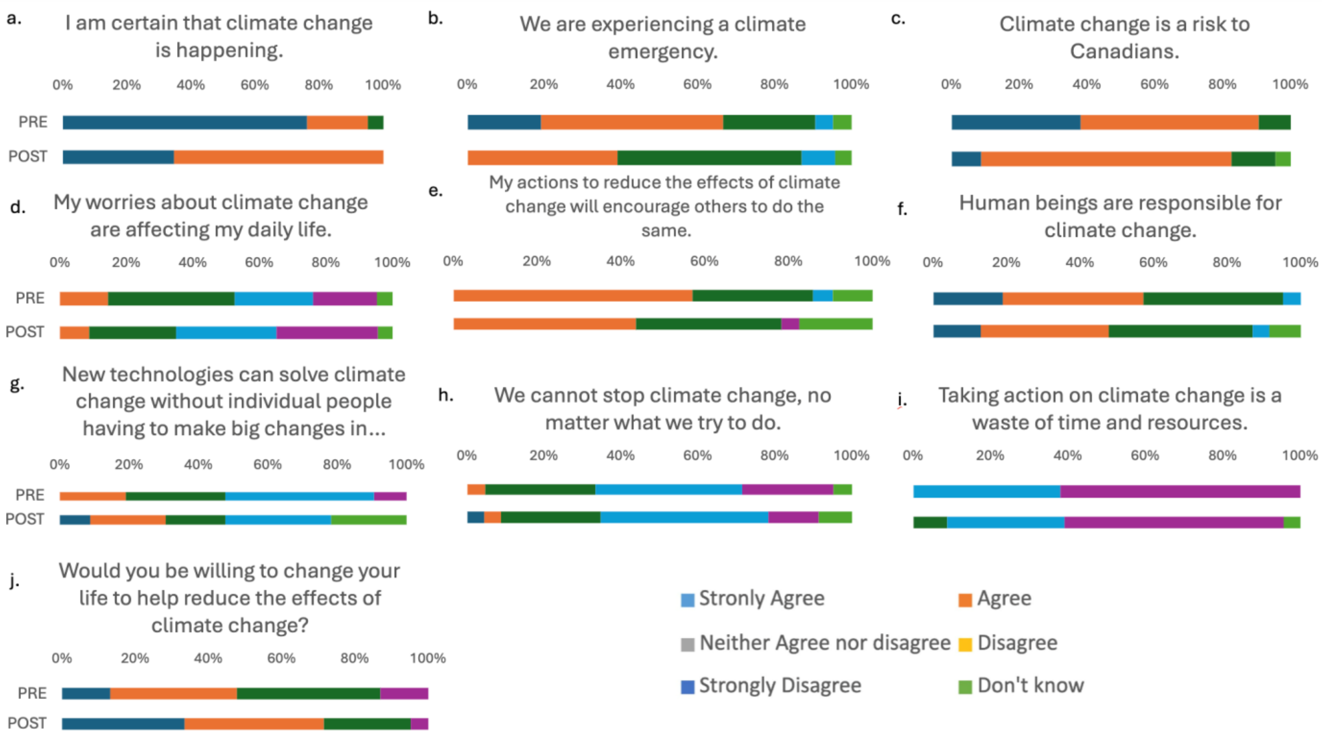
> I didn't know as much as I know now. Like, I didn't know anything about a lot of the gases. Like, I knew that gases in cars weren't really good. I just didn't know, like, how they affected it. Or, like, I didn't even know anything about the soil or anything. I did not even know that. (Chloe, 11)

> I'm very curious about climate change and I'm interested in ways to fix it. Like I go around my neighborhood picking up garbage. It's something I wanted to learn more about. (Sofia, 11)

> I think it's important that we don't help nutrient runoff. I think it's important that we start putting vertical farms in because the algal blooms will hopefully slow down and we can save the aquatic ecosystems, which we use for food and water too. (Anika, 11)

Figure 1

Anonymous Student Responses to Climate Change Effects and Actions Questions Pre- (n = 21) and Post-Participation (n = 23)



Participants were beginning to make connections between different concepts that were addressed in this unit, but there was still this sense of isolation in the way they described the issues. In what Anika describes, traditional farming is the problem that must be solved. This is representative of one main contrast in students' abilities to make connections in this unit. Some were able to critique vertical farming, understanding that it might not be a perfect alternative, and yet others were quick to accept it as the ideal solution or adaptive measure.

> It (climate change) could like, kill our plants and then we wouldn't have much to live off of and the prices could get super like, there's already been a lot of inflation, but it could get like, super expensive, which a lot of people can't afford, especially for like, fresh produce. (Jaimee, 11)

This suggests that some students were beginning to make personal connections to climate change, specifically through concerns about food affordability and inflation. Many students seemed to grasp onto isolated concepts rather than demonstrating an understanding of the interconnections among climate, food, and socio-ecological systems. 50% of this group agreed that humans are responsible for climate change at the end of this project (fig. 1, panel f), however this was not reflected in interview responses. At no point in the project did the topic of whether humans are responsible for climate change come up and yet we see this shift. While following COP28 discussions on global meat consumption, the topic of cow flatulence came up. When I asked students what they thought might happen if we ate less meat, one student responded, "then we'd have too many cows; who would eat all the cows?" as if human consumption of beef was a way of mitigating agricultural emissions. Not only is there an apparent disconnect between humans and the natural world (Louv, 2005; Sobel, 2017), but there is a growing gap between consumers and the social, economic, and social systems that produce their food. In middle class societies, young people often encounter their food in grocery stores rather than through direct involvement in the growing, harvesting, and preparation of their food (Ares et al., 2024). This limits opportunities for children to understand the interconnections between food systems and climate change (Levkoe, 2006; Sumner, 2011).

In addition to working toward an understanding of the complexity of the climate crisis, and how different sectors and natural phenomena are implicated, students began to understand the importance of collective action as a solution.

> I used to feel sad about it. But now I'm like, well, we can put it to a slow. I used to think that we couldn't do anything to stop it. But we can stop it. Everyone, collectively. (Chloe, 11)

In addition to making connections among relevant concepts throughout this project, students began to relate to one another through the collaborative aspects of this work. When asked to describe their team dynamics throughout this project, students were able to share how their team divided the roles so that everyone had something to do throughout the coding and planting process. All participants recognized the importance of communication, patience, and listening by the end of this project, which was strongly emphasized during the deliberation sessions. One student described their groups approach to collaboration as follows:

> Me and my team put it so I would go grab the plant and the other person would help me with it. And then everybody, like my team, would all have a job, and then it happened where it spilled. So, then we went to get paper towels. We worked as a group. So, people did different things, like together. (Priya, 11)

> With me and my team, we had some problems with ours, like overwatering. But we all figured it out eventually. And we figured out like about the extra layer of code. And we all worked together to put the code on and connect all the pieces together. (Avery, 11)

> We're all patient with each other. Respectful. (Raylee, 11)

Students also began to understand the value of the deliberation exercises. Working with them to listen to what others had to say and to focus on building on one another's' ideas rather than introducing new tangents was challenging in the beginning, but as the project progressed, the richness of our conversations intensified and students began to refer to what other students had said which for me what an important sign that they were beginning to truly listen to and consider the thoughts of their peers.

> They (the deliberations) were cool, because we all got to hear. You get to hear everybody else's opinions. (Anika, 11)

In post-participation survey results (fig. 1, panel j), there was a 16% increase in students who would be willing to change their lives a lot or some to reduce the effects of climate change. This was despite only 9% of this group expressing that their worries about climate change are affecting their daily lives. Post- results resemble national survey results (Schwartzberg et al., 2022) which found that 68% of students (n = 1208) would be willing to change a lot or some. These findings indicate that students may be inclined to contribute to climate solutions even when they do not feel that personally impacted by climate change.

Post-participation concept maps demonstrated an understanding of how climate change impacts algal blooms and made specific reference to vertical farming as a possible way to mitigate this, however there remained a disconnect in students' understanding of the connections between humans and the rest of the natural world.

Post-participation surveys suggest a shift to a questioning mindset (fig. 1, panel e). This could be cause for concern, however it could also indicate that students are moving beyond a simplistic understanding of climate change and are beginning to get a sense of its complexity. This interpretation is supported by interview responses, in which many students expressed a desire to contribute to climate solutions, but uncertainty regarding how to do so. Similar patterns have been documented among Canadian youth, who increasingly report concern about climate change and a desire to learn about meaningful climate action (Galway & Field, 2023).

The Importance of Direct Experience

It was clear during this project that providing the students with the opportunity to program the micro: Bits was a very enjoyable part of this project. The students' cumulative excitement when they got the water pumps working was palpable. This is not to say that the programming went smoothly from start to finish. Each group of students encountered several bumps as they endeavored to get their vertical farming system running consistently. There was a point early in the project where I felt worried that these malfunctions would cause the students to lose interest in this project, however students shared during the interviews that they valued the opportunity to engage in problem-solving to overcome these challenges.

> I think it's more fun to do it than just watch a video because say you have challenges, maybe you'll want to try it again and like do it without messing up and letting it overflow. You'll be happy once you actually do it, so you'll just want to do it again and stuff. (Stephan, 11)

By engaging in this experience directly, students got a true sense of the trial and error that is characteristic of many of the technological innovations that have been presented as adaptive and mitigative measures for addressing the climate crisis.

> I feel like on a video they wouldn't show, like if your thing would overflow, they would only show it once but not if it happened like two or three times; like you have to see it yourself. (Sofia, 11)

Several groups of students experienced their water pump over-watering their lettuce plants to the point of overflowing, requiring them to have to replant their lettuce seeds at least once. Having to do complete several iterations of their code so that it was able to provide the intended amount of water was something that helped to build their confidence, something they felt proud of.

> I'm proud, too, because, like, ours wasn't growing in the beginning, because it kept overflowing, and we kept having to replant it, and it took a long time, and we had to keep reprogramming it. I'm happy it finally planted. (Rowan, 11)

> Because it gives you a leverage that you did something for the earth...you're not just watching a video. When you're watching a video, you're not doing anything about it. If it's fun, people want to do it even more but watching a video you don't get to experience; you don't know if it's fun or not. If you go to iFly (and indoor skydiving facility), it's more fun to experience than watching. (Raylee, 11)

One student shared that she was proud of her participation during our deliberation sessions:

> (I'm proud of) my participation because I'm a shy person and I don't normally like raise my hand or participate in deliberations. I just kind of stay quiet in my seat. But this (climate change) was a subject that I'm really passionate about. (Sofia, 11)

In several of the interviews, students referred to the coding aspect of this project as fun, with many sharing that they would recommend this project to other students because of this. Other students shared that they enjoyed "playing around" with the micro: Bits and would be interested in "seeing what else they can do".

Despite the value that participants placed on having the opportunity to engage in direct experience, many still referred to the importance of sharing knowledge to collectively fight the climate crisis. When asked about the skills they developed in this unit that might help them as they seek to be agents of change, the majority shared the importance of sharing their knowledge with others.

> It's basically like a chain. Like, if you tell me, then I tell Anika, then Anika tells someone else. And all those people, not everyone will want to help, but a lot of those people will want to help out, which is creating more people knowing about it, wanting to help. (Stephan, 11)

When asked in the surveys whether they thought that acting on climate change is a waste of time and resources, just over 30% of students expressed doubt that this would be a good investment. Despite this, 71% of students shared that they would be willing to change their lives to reduce the effects of climate change an increase of 23% from pre-participation surveys (fig. 1, panel h) may be starting to ask some critical questions; they may be questioning or even doubting what they thought before. I think that this unit maybe opened the door for them, but that more time and experience would be needed to allow them to dig deeper. This need for continued learning is demonstrated by participant quotations, in that not one student was able to provide any examples of specific action other than what was shared in pre-participation concept maps (i.e. recycling, composting, driving electric cars, etc.).

Despite most students still agreeing, we see this potential onset of a doubtful mindset when students were asked before and after this project whether they thought that the work and voices of young people can inspire climate action (fig. 1, panel i). Beyond indicating in interviews that the sharing of knowledge could be a helpful approach to fighting climate change, such as the chain effect that Stephan described, students lacked awareness of specific examples of how young people might truly inspire change.

The Overpromise of Technology as a Solution to Climate Change

Solutions proposed by students in concept maps and interview responses continued to center around individual mitigation measures, despite many of the deliberative conversations centering around examples of adaptation and collective action. In this project, technology was presented as a tool primarily for climate adaptation, and as a tool for mitigating algal blooms and in some cases even climate change through the reduction of carbon emissions. The focus on vertical farming throughout this unit had the potential to imply that technology is perhaps more important or holds more promise than it really does at the moment. In the context of this work, technology was presented as a measure to mitigate algal blooms by limiting agricultural runoff, and as an adaptive measure to continue to meet the nutritional needs of a growing population despite the limitations associated with a rapidly changing climate. Prior to the beginning of this unit, 19% of the participants agreed that new technologies can solve climate change without individual people having to make big changes in their lives (fig. 1, panel h). 30% of participants agreed with this statement at the end of the project.

> Um, I think I would say do it because it's so fun. And there's so much you can learn. Um, I just think it's so much better. If we could all learn how to do it (coding), then we could help our planet a lot more. (Priya, 11)

> I'm proud that we all get to try this because not everybody gets to try this. And it's really cool. (Aisha, 11)

There is a sense of pride in being given a unique opportunity at school. This presents an individualistic mindset which is characteristic of our modern education system.

> I would (recommend this project to others) because I think it's really cool that we can help our planet just by learning how to code and stuff. (Quinn, 11)

> Well, I think it's the fossil fuels are more coming from like the farms, like, like the tractors and stuff that must go all the way across the field, and they use fossil fuels. Vertical farming doesn't use tractors, it just waters it. (Hana, 11)

Here, the student is drawing from personal experience. It was never discussed that industrial farming is problematic primarily due to fossil fuel use of machinery. The student is also presenting this as the primary problem of agriculture and suggesting that vertical farming is the best solution to this problem. This connects to the dualistic thinking that has also become associated with modernist approaches to education, which will be elaborated on in the discussion.

> I'm proud that we're just overall growing lettuce because it's so cool and unique that you can do that like, with a micro: Bit instead of regular farming. (Omar, 11)

Again, this dualistic mindset emerges, where it has to be one or the other, and the misconception that vertical farming does not require the same resources as traditional farming techniques. There is also the possibility that this project implied to some students that traditional approaches to growing food are the main problem and must be replaced. It was almost like instead of trying to mitigate the climate crisis, they were trying to find ways to replace traditional farming.

During the interviews, some students critiqued this project by making connections to what we discussed during deliberation sessions. It was clear that they had been reflecting on the true potential for vertical farming, or even technology to be a worthy adaptive measure:

> I don't think everyone should try it (growing food with micro: Bits) because it uses a lot of resources. (Skylar, 11)

> Or maybe people could do it (growing food with micro: Bits) in groups. So like we did, we did it in groups, so that it's not wasting as much materials as it would if we all did it separately. (Rowan, 11)

> I feel like it (vertical farming) would use less (fossil fuels) but also, we have to like power everything, like the lights, and if we have to power like a big panel or something to like connect it, we would still have to be using like fossil fuels, (Avery, 11)

Skylar, Rowan and Avery are making a connection between non-renewable sources of energy and the electricity that was required to operate our vertical farming setup. This was an important connection that was only beginning to emerge in this group of students by the end of this unit.

Discussions

This study comes at an important time due to the recent demands for quality climate change education (UNESCO, 2023). Despite the inclusion of climate change and environmental education in science and social studies in many school curricula, educators continue to feel underprepared to teach this subject matter in their classrooms, despite feeling the desire to do so (Schwartzberg et al., 2022; Plutzer et al., 2016; Winter et al., 2022). The findings of this study support the idea that teaching practices that center around relational ontologies and systems thinking could offer an effective approach to cultivating a better understanding of the complexity of the climate crisis, (Böhme et al., 2022; Lange, 2018). Constructivist approaches suggest that learning should happen in relation to students' prior knowledge and experiences of the world around them. Findings in this study imply that students feel disconnected from the climate crisis, yet their compassion as they learn more about the urgent need for action continues to allow them to appreciate the severity of this crisis at surface level, without feeling personally impacted by it. But is this enough for them to act or to intend to act?

The present study sought to understand how democratic deliberation and engagement in a direct experience related to climate change adaptation impacted students' understanding of climate change, climate adaptation strategies, and their personal sense of climate efficacy. Through the analysis of surveys, concept maps and interviews, four main themes emerged in relation to the questions that drove this work. They are knowledge barriers to effective climate action, the importance of relational understanding, the overpromise of technology as a solution to climate change, and the importance of direct experience.

Although knowledge is not believed to be an important predictor of self-efficacy, it plays an important role in justifying the level of concern an individual might feel regarding the climate crisis (Milfont, 2012), which an important element of self-efficacy in this context (Bandura, 1977). The results of this study indicate that participating students did experience an increase in their factual knowledge of the causes and consequences of climate change, as well as a deeper understanding of the urgency of this crisis, however concept maps and interviews revealed a sustained lacking in the depth of their understanding of the complexity of the climate crisis, and of the most effective ways of taking action on this global threat. This is not unlike what Tolppanen et al. (2022) discovered by using climate change knowledge surveys before and after a unit focused on a holistic approach to CCE. To enhance students' understanding of the complexity of climate change, it is essential to adopt an approach that consistently exposes students to the dynamic interactions between humans and the environment (Lehtonen et al., 2018). Roussell & Cutter-Mackenzie-Knowles (2019) argue for place-based experiences which engage students in the social and ecological systems in their communities. While this micro: Bit project engaged students in thinking about local environmental systems, there was limited engagement with the social dimension, indicating that technological tasks alone may be limited in their potential to capture the interconnectedness emphasized in place-based approaches. This perspective encourages learners to explore the interconnections between ecological, social, and economic systems, helping them appreciate how various factors influence climate dynamics. While this micro: Bit project afforded students the opportunity to encounter localized environmental systems along with their connections to the social dimension, they demonstrated limited engagement with social elements, hinting that technological experiences alone may not fully represent the complex interconnections highlighted in place-based approaches. The understanding of the interconnectivity of these systems, or systems thinking, is a core element of ecological literacy, which has been recommended as a feature that is paramount in sustainability education (Goodwin, 2016). Youth commonly view the world through a dualistic lens (Perry, 1970), making sense of complex issues through linear explanations and using cause-and-effect language. This is developmentally justifiable, especially when children have limited experience engaging with the complex and uncertain nature of socioscientifc issues. This was evident in interview responses, when students seemed to either see various elements as being good or bad. For example, there was no response that referred to a world in which both vertical farming and conventional farming practices could co-exist. Some saw vertical farming as a replacement for our need for sunlight, and a few referenced carbon as being something that should be eliminated. Lehtonen et al., (2018) argue for what they call a pedagogy of interconnectedness to combat “dichotomized thinking” in higher education. Teaching through a systems approach may also help to address the misconceptions that students seem to carry with them regarding the mechanism of climate change. Considered in isolation, ideas such as the thinning ozone layer or trapped carbon might make sense, but when considered more broadly, this is not so.

When it came to nurturing their specific understanding of climate change and its impacts on algal blooms, democratic deliberation appeared to be an effective tool. The following is an excerpt from my research journal after one of our deliberation sessions: *I did another deliberation with the students. I asked them to remind me what the connections were between climate change and algal blooms, and some of their answers blew me away. They understand that climate change means warmer water, and that warmer temperatures help algae to grow. They also understand that nutrient runoff from agriculture leads to algal growth, and that increased runoff in combination with warmer temperatures will lead to more algal blooms. I was super impressed.* Students demonstrated an emerging understanding of the effects of climate change on freshwater ecosystems and showed a growing understanding of how this can impact the livelihood of people who rely on healthy aquatic ecosystems. Throughout the deliberation sessions, students valued the opportunity to enhance their collaboration skills. They practiced listening to diverse perspectives and engaging in group problem-solving, particularly during the coding portion of the project. These collaborative efforts are essential "green skills," as described by Kwauk & Casey (2021), which not only facilitate effective teamwork but also prepare students to address complex environmental challenges collectively. The integration of democratic deliberation with the hands-on experience of coding micro: Bits seems to have held value for student learning. Through deliberation, students were able to explore diverse perspectives on challenges being discussed, and to adjust their own thinking. This process informed the intent and design of their coding projects. The coding portion of this project helped students to materialize their ideas, while deliberation ensures that their ideas were products of collective curiosity and critical reflection.

Paralleling findings by Drewes et al. (2018), Tasquier & Pongiglione (2017) and Holthius et al. (2014), students focused largely on the causes and effects of climate change. When it came time to discuss mitigation and adaptation strategies in post-participation interviews, students often stumbled, trying to recall our deliberative discussions in the classroom. This links back to what Drewes et al. (2018) refer to as conceptual travel, which describes the trajectory of a learned concept through different groups. In this case, I introduced concepts during deliberative discussions, or through resources that I shared with students between deliberations. Much of our time was spent discussing the causes and impacts of climate change, and this was reflected in open-ended survey responses and in post-participation interviews.

CCE must move beyond a focus on the causes and effects of climate change and provide students with opportunities to explore potential solutions. This can be challenging due to the focus on climate science in curricula. For example, in Ontario’s grade 9 science curriculum of the ten specific expectations in the sustainable ecosystems and climate change unit, only one of the ten specific expectations requires exploration of solutions to climate change (Ontario Ministry of Education, 2022a). Effective CCE should be presented in locally contextual ways such that students are able to connect to concepts being taught and make personally relevant meaning from these (Monroe et al., 2019). By engaging students with both environmental processes and the technology used to manage them, this project allowed students to personally connect with curricular content.

Students consistently expressed that their experience was not only educational but also "fun", appreciating the opportunity to "play around" with the micro: Bits, which allowed them to explore and experiment in an environment where they knew they were not being assessed. This playful engagement supports creativity, innovation, persistence, and problem-solving (Parker et al., 2022), and speaks to the importance of creativity in the engineering design process (Matos et al., 2026). These findings reinforce the importance of moving beyond the banking model of education toward participatory, experiential approaches (Freire, 1970).

One limitation of this project is that it may have oversold technology as a promising solution to the climate crisis. Prior to beginning this work, some students expressed purchasing electric vehicles (E.V.'s) as a possible solution to climate change, reflecting common narratives around the promise of technology. This reinforces the importance of sufficiently addressing both adaptation and mitigation. In this project, technology was presented as an adaptive measure. If this was the first experience in which most students had the opportunity to learn about and consider examples of climate action, this alone might lead students to think that technology is more promising, and the climate crisis not as urgent, as it really is. This overreliance on technology is what Barry (2012) calls "techno-optimism" and has the potential to reduce one's sense of urgency or personal inclination to participate actively in measures to mitigate or adapt to the climate crisis. This offers a caution to educators to avoid misrepresenting technological innovation as the primary solution to current challenges.

While much of the literature addresses climate mitigation, we must be careful not to overcompensate by overemphasizing adaptation. Involving students in examples of both is an important direction to take. Upon reflection, having more time to work with these students could have afforded us the opportunity to come back together and discuss the implications of vertical farming through a systems thinking lens, to critically examine the social, economic and environmental dimensions of this tool. This likely would have extended into the challenges of and/or the hidden costs of vertical farming, which would have supported their growing ability to think within complex systems.

Although students recognized climate change as an important issue and expressed a desire to contribute to solutions, few were able to articulate specific forms of climate action beyond sharing knowledge with others. At the same time, participants did not exhibit strong negative emotional responses to climate change, perhaps reflecting their limited direct experience with its impacts and the relative insulation of middle-class North American lifestyles from many of its immediate consequences (Kaijser et al., 2013; IPCC, 2023). Blake's (1999) framework offers one possible explanation for this gap between concern and action. Students may have lacked the sense of personal responsibility, efficacy, or practical capacity needed to translate their growing awareness into meaningful engagement. Similar barriers have been identified in relation to developmental readiness (Vergunst & Berry, 2022) and the influence of parental worldviews (Liu & Green, 2024).

These findings also highlight the ethical responsibility associated with climate change education. While increasing awareness of climate risks is an important component of CCE (Monroe et al., 2019), emphasizing threats without providing opportunities for meaning-making, dialogue, and action may contribute to feelings of anxiety, helplessness, or despair (Ojala, 2021; Pihkala, 2020). Educators therefore have a duty of care to cultivate both critical awareness and constructive forms of hope and agency. In this study, deliberation, collaborative problem-solving, and engagement with potential mitigation and adaptation strategies were intended to position climate change as a challenge that can be addressed collectively rather than as an overwhelming problem beyond students' control.

It is evident that project-based learning effectively supports student engagement. Many students expressed that they valued being given the opportunity to learn experientially and to make mistakes and learn from these, rather than learning through more traditional forms, such as the banking model of education (Freire, 1970). This presents a call to action for science educators and anyone else seeking to teach in a way that supports behavioral engagement to adopt pedagogical styles reflective of an experiential approach (Dewey, 1938). As the facilitator of this project, I was struck by how often students referenced the value of being trusted to make decisions, test ideas, and learn from mistakes. Their enthusiasm appeared to be rooted not only from the hands-on nature of this project, but from the autonomy they were granted to pursue their own ideas, troubleshoot challenges, and develop solutions. This suggests that experiential learning may be particularly impactful when accompanied by authentic opportunities for student agency, allowing learners to see themselves as active participants in knowledge construction and problem-solving.

Conclusion

The findings of this study intend to support a more comprehensive understanding of how to empower young learners as active, informed citizens capable of addressing climate challenges, fostering a sense of agency, and hope for the future. It highlights the importance of involving students in direct experiences related to climate change adaptation, and addressing commonly held misconceptions regarding the climate crisis. It reinforces a call to action to focus on cultivating an understanding of key scientific concepts that are foundational to an understanding of the climate crisis. This includes concepts such as the carbon cycle and its connection with the atmosphere, along with the misconceptions regarding the Earth's atmosphere and the ozone layer. This should be a priority in teacher education programs, and not solely the responsibility of science teacher educators. This should be widely addressed such that all educators feel prepared to address this in their classrooms as they seek to integrate CCE into a variety of subject areas.

Rather than focusing on isolated challenges, meaningful CCE means authentic engagement with the complexity of socio-ecological challenges associated with the climate crisis. This includes being able to critically evaluate the viability of proposed solutions, whether they be mitigative or adaptive, and being able to assess their promise on how other elements of this complex web are implicated (Lehtonen et al., 2018). It means understanding the meaning of sustainability and how solving one environmental or climate issue does not necessarily mean that this supports the greater mission for a sustainable planet until we have considered its impacts on the social, economic and environmental dimensions of our world (Pawlowski, 2008). CCE should seek to support students' ability to understand the dynamic interplay between humans and the surrounding environment, so that they can confidently make decisions that support the wellbeing of all facets of their communities. There are many ways of providing these opportunities to students, and it is important to continue to explore these and share effective examples throughout the greater education community, however some promising traits of such experiences include those which involve students with real issues in their communities and engage their thoughts and ideas in an inclusive caring environment. Students should be given the opportunity to explore new ideas and to engage in the cyclical nature of innovation, which fosters the development of soft skills that underpin the level of persistence that is required of us as we seek to find solutions to some of our greatest challenges.

The persistence of climate-related misconceptions in this project suggests a need for future research to explore systems thinking pedagogies that support students' understandings of the interconnections between social, economic, and ecological systems implicated in the climate crisis. These projects should consider providing students with frequent opportunities to construct and revise concept maps and feedback loops, and perhaps more varied forms of model-based-reasoning.

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