THESIS

WHERE ROOTS RUN DEEP: FOSTERING YOUTH ENVIRONMENTAL MOTIVATION THROUGH LIVELIHOODS IN RURAL PLACE-BASED EDUCATION

Submitted by

Sophie Maksymkiw

Department of Biology

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Master's Committee:

Advisor: Meena Balgopal

Greg Newman
John Mola

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ABSTRACT

WHERE ROOTS RUN DEEP: FOSTERING YOUTH ENVIRONMENTAL MOTIVATION THROUGH LIVELIHOODS IN RURAL PLACE-BASED EDUCATION

As youth stare into the beast of climate change, it is important for them to be prepared and feel agentic in attacking the hurdles of climate change. Youth students will be among the most affected by climate change in the future, however, due to the current political state of the US and the lack in access to climate change curricular materials, teaching climate comes with a few challenges (especially in rural school districts). Additionally, youth in the US are less likely to be motivated to act on environmental issues in comparison to youth in other countries. To target student environmental science motivation in an intermountain west region of the US, we grounded this study in Situated Expectancy Value Theory where we investigated how values, identity, and expectations of success contribute to motivation. We designed a Place-Based Education (PBE) climate change module where students engaged with participatory science data framed around phenological changes that are occurring to their local bumble bees and plants. Students of two middle school teachers, one in a suburban school (n=56) and one in a rural school (n=42) implemented the module. To measure the effects of environmental motivation conferred by the module, students took pre and post surveys. We found that identity increased in suburban students and values decreased in rural students after interacting with the module. Motivation in rural students started out lower and ended lower in comparison to suburban students. These differences revealed that rural students should engage in community action following a PBE environmental to avoid potential disempowerment. Through environmental contextualization of the two populations, we found a difference in experiences, knowledge types, and differing scopes of powerlessness between the two teachers, highlighting how the rural region experiences the environment more directly, leading to an effect on their livelihoods. These results suggest that livelihood validation and community environmental actions as promising integrations to rural curricula.

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PREFACE

Rapid, human-induced climate warming over the past century has driven unprecedented changes in both ecological and social systems, altering ecosystems and livelihoods worldwide (IPCC, 2023). Terrestrial and marine ecosystems, in particular, are experiencing changes from shifting climate and weather patterns, which intensify physiological stress on organisms sensitive to environmental change (Doney et al., 2012; Malhi et al., 2020). This can result in species adapting by shifting their geographic range out of intolerable conditions and can lead to community restructuring (Parmesan & Yohe, 2003; Thurman et al., 2020). Ecological responses can trigger cascading effects that extend into social systems, potentially disrupting livelihoods and human health by reducing food security, nutritional quality, and economic stability (Pecl et al., 2017; M. R. Smith et al., 2015, 2022; IPCC, 2023). For instance, shifts in pollinator-plant synchrony can impair ecosystem services, leading to similar socio-economic consequences (Pecl et al., 2017; IPCC, 2023). These disruptions may ultimately undermine essential human needs and well-being.

Although climate change has negative effects across social-ecological systems, collective action is limited across the United States relative to other North American regions due to differences in perception to climate-risk and political polarization (IPCC, 2023). Climate literacy can foster empowerment amongst individuals which can lead to climate action (Muccione et al., 2025; IPCC, 2023). Climate action can take many forms, such as civic engagement and community advocacy for environmental policies. Aligned with much of the existing literature, the Sustainable Development Goals (SDGs) emphasize the importance of Quality Education (SDG 4) as a foundation for a sustainable future (United Nations, 2015). Additionally, education plays a crucial role in advancing Climate Action (SDG 13), highlighting its interconnected impact on global sustainability efforts to achieve collective community engagement across the world in climate change issues (Filho et al., 2023; United Nation, 2015). Collective action can start with youth, especially due to their high potential to be agents of change (Han & Ahn, 2020). Designing curricular materials that nurture this potential is essential—not only for empowering young people and shaping their futures, but also for fostering broader societal transformation.

The first chapter in this thesis, is titled "Pollinators, People, and Place-Based Data." This is about a participatory-centered module that teaches students about how climate change impacts social-ecological systems through examination of a local, authentic dataset. This chapter has been submitted to the *Science Teacher* and is in revision. The second chapter is titled "Where Roots Run Deep: Fostering Youth Environmental Motivation Through Rural Livelihoods in Place-Based Education." This section is about how the module from chapter one affected student motivation to engage in their communities to solve environmental problems. We plan to submit this chapter to the *Journal of Research and Science Teaching* with Rob Behrens and Zach Boor, two middle school teachers in whose classes the data were collected.

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Pollinators, People, and Place-Based Data

1 INTRODUCTION

The buzzing of a bumble bee is one of the most reminiscent signs of spring. However, due to climate change, pollinators and their vibrant flowers are increasingly at-risk. Pollinating insects are one of many groups susceptible to global climate change (Harvey et al., 2022). Yet, many teachers are not sure how to implement engaging, inquiry-based lessons about a changing environment and its effects on vulnerable populations. This may be, in part, due to the lack of teaching resources (i.e., datasets) available as well as the perception that the topic is controversial (Nation & Feldman, 2021). Introducing climate science through cases of pollinator-plant interactions and phenology, though, with authentic datasets can increase data literacy (Schultheis & Kjelvik, 2020). Data literacy is becoming increasingly important for everyday decision making, and it is imperative for students to develop the confidence and knowledge to interpret data and graphical images. Here, we describe a curricular module for high school students that integrates climate change, data literacy, and participatory science, equipping students with the knowledge and competencies to make informed environmental decisions.

2 POLLINATOR PHENOLOGY MODULE

In this module, students will learn about participatory science and how these projects generate data in local communities (Figure 1.1; Supplemental Materials). They will read about adolescent peers who are participatory scientists. Through an analysis of a participatory science

[1] Maksymkiw, S., & Balgopal, M. (in review). Pollinators, people, and place-based data. Manuscript submitted for review to *The Science Teacher*.

dataset, with abiotic (temperature, precipitation) and biotic (phenological bumble bee and flowering plant observational) data, students will test hypotheses, as well as identify patterns in graphs. Finally, they will develop a scientific argument based on their findings, share it with the class, and receive feedback from one another. Our goal was for students to engage in the authentic practices of environmental science from start to finish, so they can identify as both scientists and engaged community members.

About Participatory Science

Some research projects rely on a wide range of members who help collect data. These participatory science projects depend on volunteers to collect and share data, often through public platforms, like iNaturalist or ebird. While the terms citizen science and community science are becoming more common, participatory science is more inclusive of diverse individuals and identities because it recognizes that public engagement in science differs from science specifically dedicated to addressing community concerns (Lin Hunter et al., 2023). In other words, sometimes data are collected by volunteers without a motivation that is defined by the project. Birders and naturalists often like to track their own observations of wildlife and plants, for example. Yet, scientists can use these data collected over large geographic areas and time to study patterns and trends. When students are involved in such endeavors, it can increase their confidence, sense of agency, interest, and motivation to address social-ecological issues (Ballard et al., 2017). However, creating an authentic participatory dataset can be time-consuming and potentially overwhelming for teachers.

Ballard, H. L., Dixon, C. G. H., & Harris, E. M. (2017). Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation. *Biological Conservation*, *208*, 65–75. https://doi.org/10.1016/j.biocon.2016.05.024

Lin Hunter, D. E., Newman, G. J., & Balgopal, M. M. (2023). What's in a name? The paradox of citizen science and community science. *Frontiers in Ecology and the Environment*, *21*(5), 244–250. https://doi.org/10.1002/fee.2635

Figure 1.1 Participatory science description. Participatory science is a way for all community members to engage in scientific endeavors, specifically monitoring and data collection.

2.1 Engage: am I a scientist?

This module begins with introducing students to participatory science. Students discuss what this term means as a class or within their small groups and watch a video about a participatory science project (about the timing of cherry tree blossoms). Then, they explore a website (https://smaksymk.wixsite.com/participatoryscience) and read about their peers who have been involved in participatory science projects within their local community. Students can also learn about participatory science projects within their local community by clicking on the 'Get Involved' tab on the website. If students do not find a project they are interested in, they can click on the link, citsci.org, which describes hundreds of participatory projects.

To wrap up the first day, students can immerse themselves in the role of participatory scientists by engaging in an interactive iNaturalist - Seek activity. iNaturalist is a platform where identifications can become verified by experienced community members and/or expert taxonomists. Depending on classroom resource availability and safety policies, students can either use their phones or other electronic device to download the 'Seek' app. This app allows the public to identify organisms with a photo. Simply by holding the phone camera up to a plant, animal, or fungus, the app will identify most organisms to species. We encourage students to use caution if they are getting close to bees when taking photos to prevent the insect from stinging. It is also advisable to find out if students have any allergies to certain plants or insects, so teachers can be prepared. Optionally, after students have collected observations, they can upload their identifications to iNaturalist by linking their Seek account to iNaturalist. This activity can be done during class or as a homework assignment, although it is not required to complete the rest of the module.

2.2 Explore: I can research important topics like a scientist

In this section of the module, students learn about pollinator-plant phenology and how the interaction is being affected by climate change. Students first engage in a class or small-group discussion about seasonality and abiotic variables that can lead to a change in seasonality. Teachers should introduce students to the concept of phenology, how it applies to pollinators and plants, and the possible implications of pollinator-plant misalignment (Figure 1.2). Plants can be impacted by early-season frost exposure which could then impact pollinator foraging (Inouye, 2008). The concept of "phenological mismatch" is an extension term that may help explain why phenology is studied by scientists interested in the impacts of climate change. The phenological mismatch hypothesis is actively studied and debated. Although there are examples of organismal phenological changes (e.g. generalist birds and insects), cases of multitrophic mismatches are far fewer (Inouye, 2022). This is a great way to engage students in a discussion about how hypotheses are constructed. Although many students think of hypotheses as "educated guesses," they are, in fact, tentative explanations informed by preliminary data or case studies. Scientists test hypotheses to better understand how generalizable a scientific explanation is across organisms, contexts, and field sites.

Phenology and Pollinator-Plant Interactions

Phenology is the study of the timing of lifecycle events and behaviors which are controlled by the climate (reviewed by Inouye, 2022). Abiotic factors such as precipitation, temperature, and photoperiod are all important in regulating lifecycles. With a rapidly changing climate, phenology of essential ecosystem interactions such as pollination could become disrupted. Although, it is difficult to generalize this across pollinator populations because some pollinators are significantly more affected than others. However, it is known that in the

Mountain West that flowering timing is arriving earlier than in previous decades and can lead to a lower seed production due to early-season frost (Inouye, 2008). Shifting timing of plants can also affect some bumble bee species due to shifting floral resource availability. In other words, if bumble bees are foraging for nectar when plants have yet to or have not yet produced nectar, it can impact the bees' ecology. Hence, identifying matches and mismatches of biological events can sometimes be explained by changes in abiotic conditions.

Inouye, D. W. (2008). Effects of Climate Change on Phenology, Frost Damage, and Floral Abundance of Montane Wildflowers. *Ecology 89*(2), Article 2. https://doi.org/10.1890/06-2128.1

Inouye, D. W. (2022). Climate change and phenology. *WIREs Climate Change*, *13*(3), Article 3. https://doi.org/10.1002/wcc.764

Figure 1.2 Phenology description. Phenology is the science of biological timing, such as when pollinators emerge and when plants flower.

The USA National Phenological Network (NPN) database is an excellent interactive mapping tool that we found students to enjoy (Figure 1.3). Students will navigate the website through a guided activity that visualizes how spring is arriving earlier than it historically has in the U.S. By adding a bumble bee layer to their maps of flowering timing, students can consider how pollinator activity will be impacted by climate change. Students who need more of a challenge can view the different visualization types (scatter plot, line graph, time series) and decide which representation of data is best. After this activity, students will assess how the effects of climate change on seasons, plants, and pollinators may impact the interconnected, social-ecological system and the individual implications to each system. Shifting abiotic variables can disrupt trophic interactions (e.g., pollination) in complex and context dependent ways with unintended consequences (Inouye, 2022). For example, when ecosystem interactions are impacted in agricultural production and lead to decreased pollination services, it can impact economic livelihoods and decrease food security (Khalifa et al., 2021).

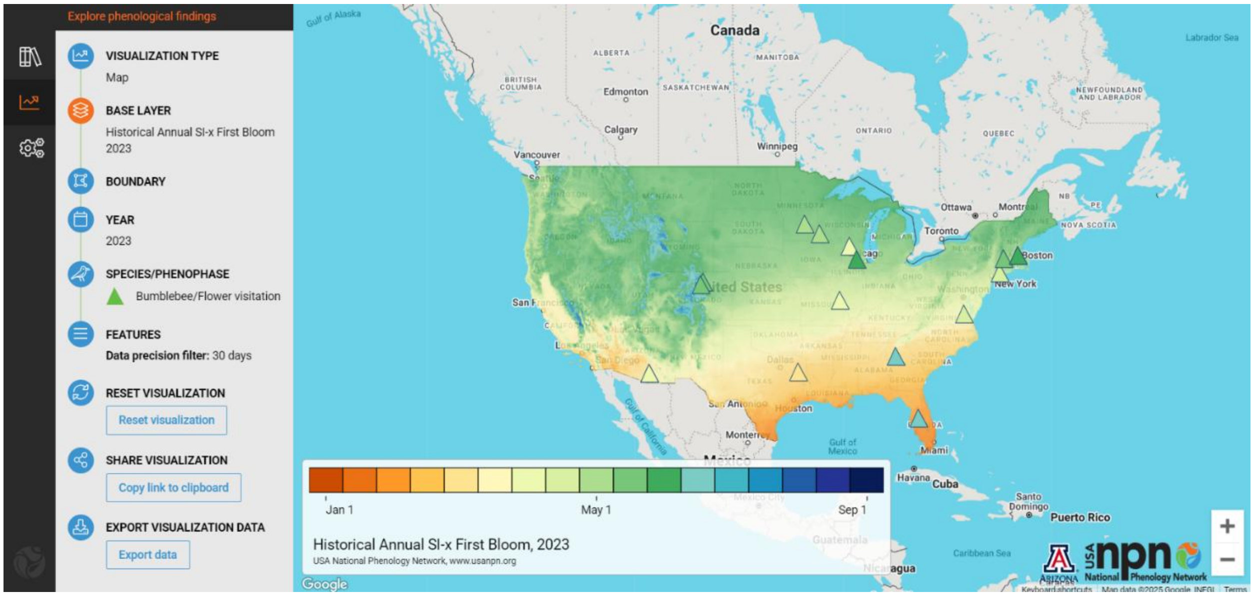

Figure 1.3. National Phenological Network Data Visualization Tool. Historical annual timing of first blooms and bumble bee visitations in the United States in 2023.

2.3 Explain: I know how to design studies like a scientist

One goal of science teachers is to help students build the confidence and competencies needed to pursue science after high school. In this section, students design their own research study and use authentic data to test their hypotheses.

First, students must familiarize themselves with the datasets. They identify and explain what each of the variables mean. They can do this by accessing the Participatory Science website they used earlier by going to the 'glossary' tab, or by going through the terms as a class. Within the dataset there are biotic phenophase data (for plants and bumble bees) and abiotic climate data. Together, these variables can help them answer a question about how climate change is affecting plant-insect interactions.

After students have defined each variable, they develop a hypothesis based on knowledge learned from the previous day. As teachers are aware and what we have found when helping several classes with this module, students can find creating a hypothesis to be a daunting task.

One solution is to ask students to formulate a research question based on the given variables and answer the question in the form of a hypothesis. Teachers can also choose to provide one (or more) hypotheses that the class tests together. If students create their own hypotheses, there are guiding questions within student and instructor materials that can provide clarity by asking students to make predictions (i.e., expected outcomes). This allows students to work backwards and think of hypotheses (i.e., tentative explanations). Example questions include:

- *When do you think the timing of phenological events of flowers in the dataset will change over time? Earlier/later?*
- *How do you predict plants to be affected over time by temperature and/or precipitation?*

After students have developed a hypothesis, they can complete a tutorial that walks them through how to create a graph in Microsoft Excel or Google Sheets (Supplementary Materials). This closing activity can be done as a class, within groups, or independently and will prepare students for the following class period. We found that advanced students enjoyed working independently, but most students needed to create graphs as a group.

2.4 Elaborate: I can reach conclusions based on findings like a scientist

Data and graphical literacies are two competencies tightly aligned to being scientifically literate (Gormally et al., 2012). Now, students will test their hypotheses using graphs that they create. We recommend that teachers scaffold graph interpretation by reminding students how to read these. We found several prompts to be helpful (Figure 1.4).

1) What are the X and Y axes? Recall what these variables mean.

2) How much data is represented in the graph? Is this enough for the trend to mean something?

3) Look for a pattern in the figure.

a. Is there a trend in the data?

b. An increase/decrease?

c. Randomness?

3) Write a conclusion about the data in the graph.

e.g. The trend in the data is showing that [insert species name] is [flowering/occurring] [earlier/later/no change], than [it has in the past/over certain years]. Therefore, I can conclude that because of this, [flower species/bumble bee species/the interaction] is being [affected/not affected] by climate change.

Figure 1.4. Student guiding questions for graph interpretation. These question are within the student and teacher guides to help students reach a conclusion about the graph.

For example, the trend in the data is showing that *Delphinium nuttallianum* is flowering earlier over time (see Figure 1.5), and the first day of bare ground is occurring earlier (see Figure 1.6). Therefore, I can conclude that because bare ground is being exposed sooner, likely due to increased temperature and reduced snowpack, *Delphinium nuttallianum* is being affected by climate change.

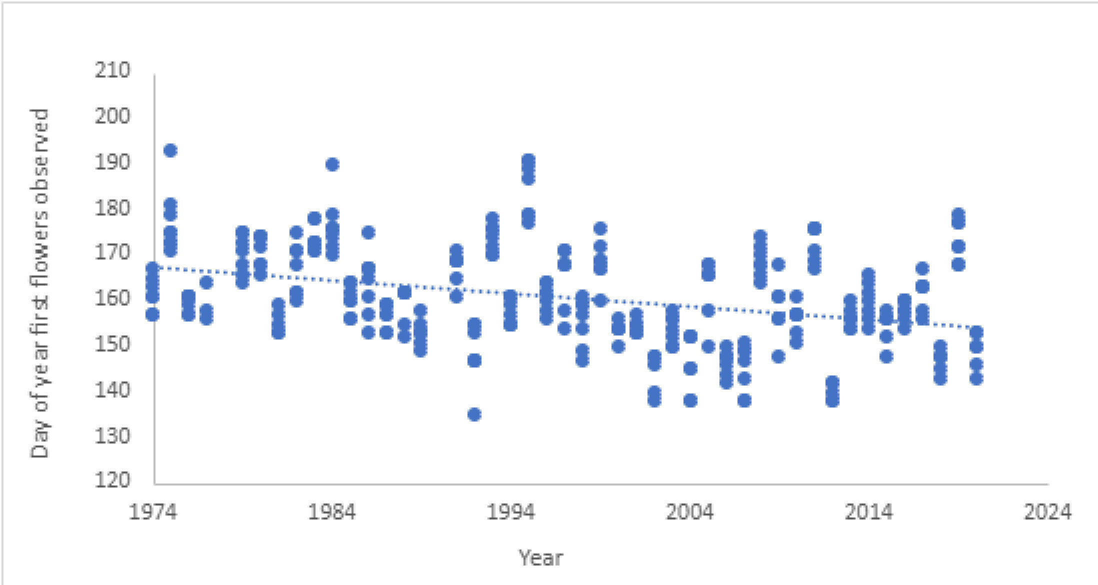

Figure 1.5. *Delphinium nuttallinium* of first flowering day over time at the Rocky Mountain Biological Laboratory, CO from 1974-2020. From "Investigating effects of climate change on the phenology of subalpine wildflowers using a 45-year dataset," by D.W. McNutt, N. Underwood, and B.D. Inouye, 2023, *Teaching Issues and Experiments in Ecology, 19,* Practice #14. Copyright 2023 by McNutt, Underwood, & Inouye. Licensed under CC-BY-NC 4.0.

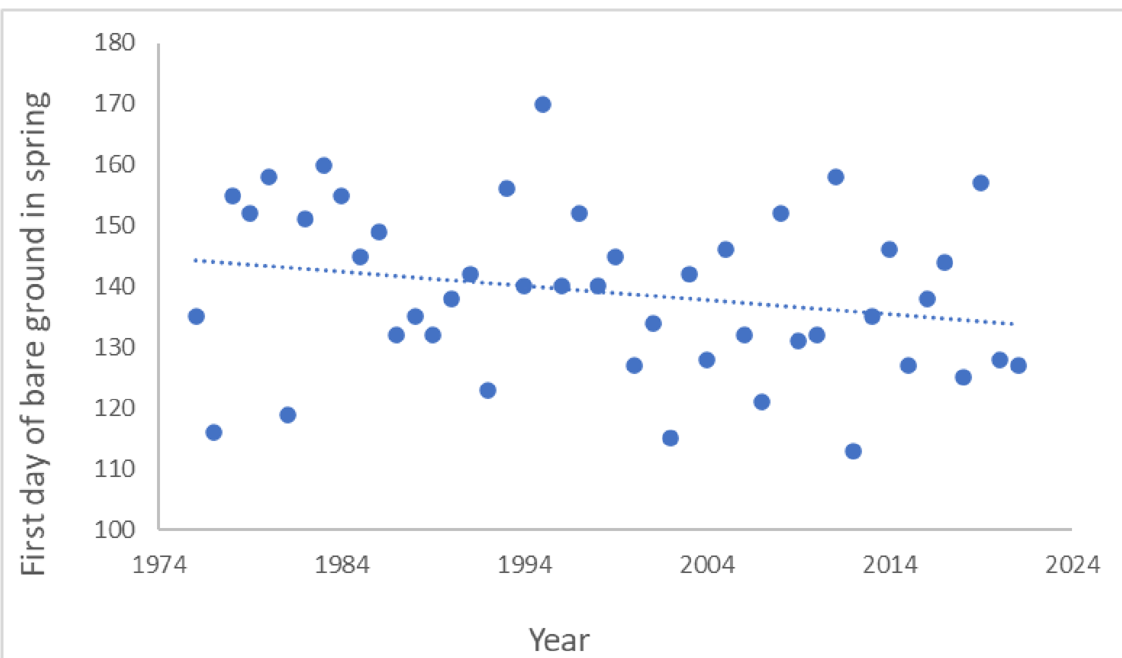

Figure 1.6. First day of bare ground at the Rocky Mountain Biological Laboratory, CO from 1974-2022. From "Investigating effects of climate change on the phenology of subalpine wildflowers using a 45-year dataset," by D.W. McNutt, N. Underwood, and B.D. Inouye, 2023, *Teaching Issues and Experiments in Ecology, 19,* Practice #14. Copyright 2023 by McNutt, Underwood, & Inouye. Licensed under CC-BY-NC 4.0.

Students are encouraged to discuss further how their results impact the social-ecological system. After they have written conclusions about each graph needed to test their hypothesis, they construct a synthesis of their findings using the claims-evidence-reasoning model (McNeill & Krajcik, 2011).

2.5 Evaluate: I can give and accept critiques like a scientist

Scientists engage in peer review when sharing their results at conferences or submitting manuscripts to journals. Peer review is an important opportunity for scientists to clarify how they make claims about their evidence. We encourage teachers to give students the opportunity to present their written arguments to their classmates. In one class that tested this module, students printed out their scientific posters, circulated around the room, and pasted sticky note feedback onto their classmates' posters (Figure 1.7). We provide a peer feedback worksheet that students can fill out as they are listening or circulating around to different posters (Supplemental Materials).

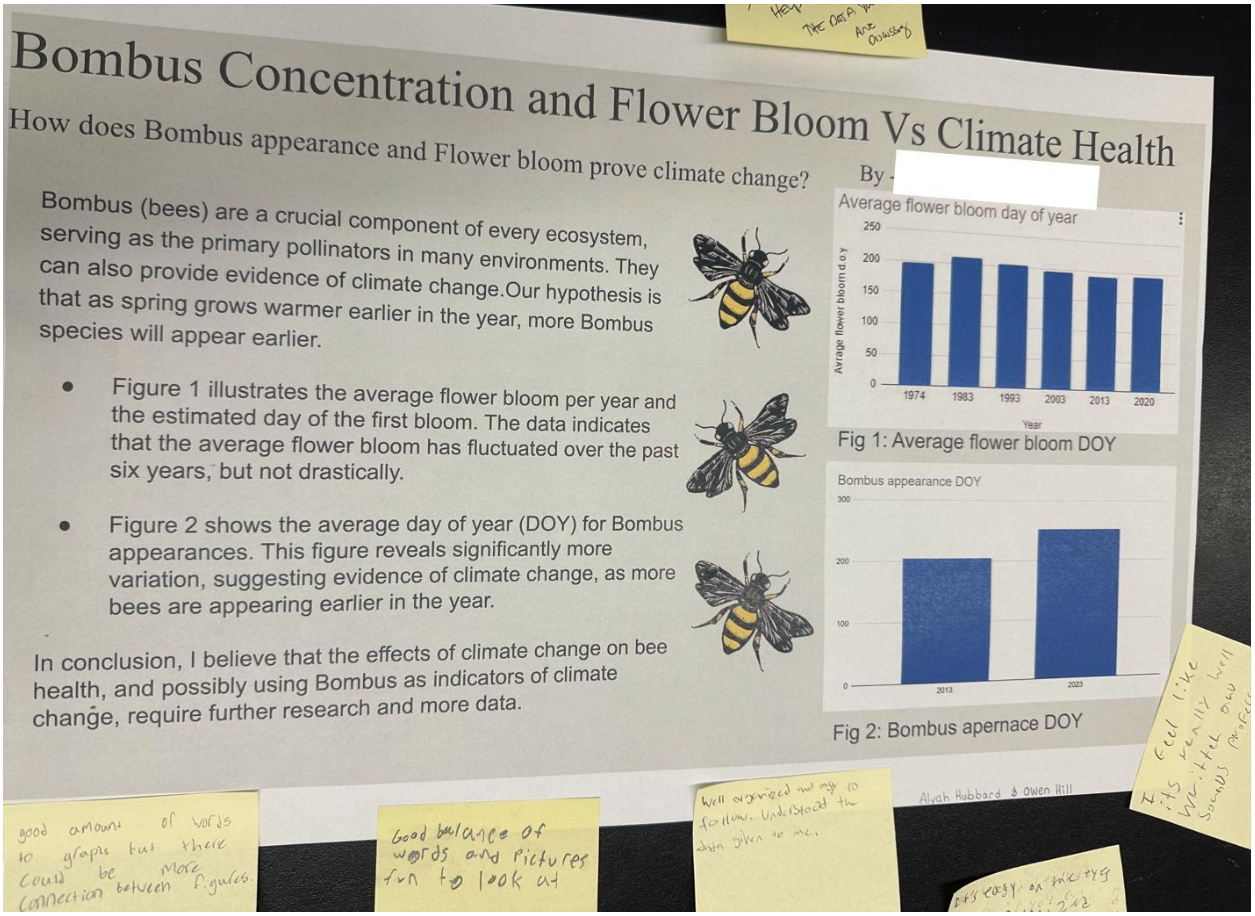

Figure 1.7. Student poster example. This student's poster examined *Bombus* abundance and how it aligns with flowering day of year. Posted notes are attached by other students with feedback.

If teachers want students to engage in self-evaluation, students can write about in which aspects of the module they excelled and where they still need to grow. This is an opportunity for them to gain a deeper self-awareness, identify specific strategies for improvement, and set personal goals for future learning experiences.

2. 6 Poster Assessment

Students create a scientific poster as a summative assessment (Newbrey & Baltezore, 2006) (Table 1.1), but this can be modified depending on student needs. Teachers may want groups to work together or to create other documents summarizing their findings (e.g., infographic, written report). We encourage teachers to show example posters (Supplemental

Materials) to their students but to determine how to differentiate the expectations for their students based on their level and needs.

Table 1.1 Rubric for the phenology study poster assignment.

	0 Points	**½ Points**	**Full Points**
Title	No title.	Title is not descriptive of a key finding or their process, but there is a title.	The title was informative of the project. Highlighted a key finding or described their process.
Background/Purpose	Doesn't provide background/purpose information or doesn't mention environmental conditions.	Mentions phenology, environmental shifts, or the SES, but not all three.	Explains the clear rationale for the study. Mentions, phenology, environmental shifts, and the SES.
Hypothesis	Does not provide a hypothesis that aligns with pollinators, phenology, or environmental conditions.	Explains clearly but does not provide enough evidence for why.	Explains the clear rationale for hypothesis with at least 2-3 pieces of supported evidence.
Methods	Does not explain where the data was obtained, how they graphed it, or a rationale.	Explains where/how data was obtained, description of the dataset, analysis approach, or rationale, but not all three.	Methods explained where/how data was obtained, description of the dataset/field site location, analysis approach, and rationale.
Results	Doesn't include graphs or summaries.	Includes graphs or summary, not both. Or includes graphs and summary but does not interpret correctly.	Includes graphs and summary of results. Summary interprets graphs correctly.
Graphs	Doesn't include graphs.	Includes only 1 of the graphs or figures with labeled axis. Graphs or figures chosen do not	Includes all 2-4 graphs. Graph's axes are labelled. Figures align with the

		align with the hypothesis.	hypothesis they chose.
Conclusion	Synthesizes results incorrectly or doesn't include a conclusion.	Synthesizes results but doesn't explain the broader implications of the study.	Synthesizes results and attempts to explain how the results of one graph explain the other or how you can apply these results to broader implications and/or SES.
References	Doesn't include a reference section.	Includes a reference section but doesn't list any references.	Lists all references used and includes data citation.

2.7 Differentiation

This module can be easily differentiated by scaling down materials for the diverse needs of students. Instead of having students create their own hypotheses, teachers can decide to create one as a class or supply a few options to choose from. Alternatively, instead of having students create their own graphs in excel, teachers can provide completed graphs and work through interpretation as a class. Teachers can also choose to have each group work on one section of the poster/other written synthesis and create a collaborative project across the class.

3 CONCLUSION

Although teaching climate change and data skills might be overwhelming, this module is designed to address some potential obstacles. Teachers who tested this module found the materials valuable, appreciated its flexibility, and intend to incorporate it into their future lessons. We loved seeing that some students expressed excitement when first learning about other young adults who were engaged in local environmental research efforts as participatory scientists. Although not all students may have the chance after school to engage in local projects, this module can give students a chance to have a similar experience as a participatory scientist. Most importantly, students can explore the types of data that scientists examine when trying to better understand the impacts of a changing climate on plants and pollinators. Our hope is that students will be motivated to learn more about their local environmental issues and become engaged.

CHAPTER 2

Where Roots Run Deep: Fostering Youth Environmental Motivation Through Livelihoods in Rural Place-Based Education

1 INTRODUCTION

Climate change has negative effects across social-ecological systems. If individuals do not understand how their actions contribute to environmental changes, they are less likely to engage in collective action (Mori & and Tasaki, 2019). For youth, this is particularly critical because they will be among the most affected by climate change, experiencing the long-term consequences of climate change (IPCC, 2023). Perceiving climate risk and feeling that they have control to change their world are two important first steps for youth to feel motivated to both prevent and mitigate the impacts of climate change (Pickering et al., 2020). While K-12 teachers are aware of the importance of mobilizing their students to learn about environmental issues, climate change is a topic that they find difficult to teach (Beach, 2023). In part, this is because of the hyperpolitical nature of climate change and the potential for push-back from students, parents, and community members (Monroe et al., 2019; Scheer et al., *in revision*). However, teachers need support in accessing and developing relevant, place-based lessons that allow students to explore authentic data through engaging activities (Kumar et al., 2023).

Increasing students' environmental knowledge is not enough to promote pro-environmental behaviors (Corner et al., 2015). Students' values shape their intentions and motivations to act in pro-environmental ways (Balundė et al., 2020). Beliefs and increased feelings of self-efficacy also motivate youth to advocate for environmental issues (Corner et al., 2015), similar to the impacts of increased environmental identity (Balundė et al., 2020). Self-efficacy describes the belief that if one invests effort in a task, they can achieve it (Priya & Thenmozhi, 2021; Qin et al., 2024). Interestingly, youth in the United States have been grouped as less willing to be environmentally engaged compared to youth in other global north countries (Lee et al., 2020). This may be explained by high levels of anxiety, feelings of betrayal, and a sense of powerlessness in addressing future climate challenges (Hickman et al., 2021). There are some cases, though, when youth expressed empowerment to learn more and to take environmental action (Trott, 2020). Because youth have the potential to be agents of environmental change (Han & Ahn, 2020), teachers need support to encourage this.

As with youth, increased climate knowledge is insufficient to motivate teachers to act. Teachers may not teach climate change content for several reasons, Often, teachers do not have access to authentic, climate change teaching resources (Nation & Feldman, 2021; Plutzer et al., 2016). They may avoid teaching it because it is often viewed as controversial, and they may fear retaliation from community members (Monroe et al., 2019; Nation & Feldman, 2022). Such feelings are exacerbated in rural parts of the United States, where climate-risk perception can be lower in comparison to suburban and urban areas (e.g., Scheer et al., *in revision*, IPCC, 2023). These fears can be exacerbated when climate education is framed around 'anthropogenic blame' and economic finger-pointing, as such approaches can increase student resistance to the concept especially in association with an individualistic worldview (Stevenson et al., 2014). Instead of promoting engagement, these frames may reinforce students' defensiveness, making it harder to connect them to the importance of human-driven climate change and potential solutions. The community and educational landscape is one that is not always conducive for teachers to teach climate science, even if they believe that their students should learn the content.

We recognize that science teachers seek curricular materials that engage their students in making sense of climate data without becoming over-political. In this study, we developed a module for suburban and rural students around an authentic dataset that allows students to explore how climate variables may affect pollinator-plant interactions. The phenology module was designed using regionally relevant data from participatory science sources. We trained secondary teachers across the northern part of our state in how to use and modify lessons within the module. Here, we describe student outcomes (identity, values, beliefs, and motivation) after their teachers at their respective schools (one rural and one suburban) implemented the modules. Additionally, we investigated how environmental context in association may affect student outcomes. We asked: How does a phenology, place-based education module (using participatory science data) affect rural and suburban secondary students' motivation to be engaged in local environmental science? We predicted that participants in both contexts would demonstrate increased motivation to be environmentally engaged community members because the module focused on regionally relevant and authentic data, featured environmentally engaged youth from the area, and provided an entry point for being a participatory scientist.

1.1 Place-based Education

Integrating place-based education (PBE) into curriculum can bridge secondary students and teachers' needs in the context of climate change. Place-based education integrates the students' lived experiences into their learning, helping them connect and apply new knowledge to their own lives. Curricula designed with PBE usually is experiential, includes locally relevant content that includes a shared community experience, draws on interdisciplinary concepts, and can lead to civic engagement (Wright et al., 2021). PBE can help teachers overcome the challenges of teaching climate change by making the content more relevant to students, especially when the topic is framed in a way that avoids the controversial pieces of teaching climate change.

By framing local pollinators and plants—and their potential phenological responses to climate change educators can take a less controversial approach to teaching climate change. Phenology is the study of lifecycle events and essential behavioral patterns that are controlled by climate variables and circadian rhythms (e.g. pollination, migration, hibernation). Phenology is shifting due to climate change through changes in temperature and precipitation (Inouye, 2022). This is leading to an earlier spring and causing flowers to shift their flowering phenology. Although interspecific responses vary, pollinators are either adapting to the shifted floral bloom timings, and/or generalist pollinators are buffering the pollination of flowers that specialists cannot (Inouye, 2022; Kharouba & Wolkovich, 2023). However, frost tolerance of plants can lead to reduced reproductive fitness (Inouye, 2008), which can then affect insect pollinators through asynchronous pollination. This is specifically the case for bumble bees (Pardee et al., 2018). Designing climate change lessons that engage students in investigating data of their local bumble bees and plants with PBE highlights data literacy as a learning outcome and anthropogenic cause shifts away from the focus.

1.2 Data literacy

Climate change education can be used as a gateway to teach data literacy, further isolating climate change from anthropogenic causes. American youth and adults lack data literacy competencies (Frank et al., 2016). Through the analysis of authentic datasets, youth can increase their understanding of how to interpret data (Kjelvik & Schultheis, 2019). Furthermore, some researchers argue that knowing how to make sense of climate data is a precursor to becoming engaged in community decision-making (Bhargava et al., 2015; Ellwein et al., 2014).

Authentic datasets are those that reflect real-world measurements, rather than hypothetical, cleaned datasets developed for class activities. Authentic data sets may include more information than students need for their lesson, necessitating that they determine which data are relevant. Because it is not practical for teachers and students to collect their own robust and complete data set in a module on climate change, we collated our own data set using participatory science databases.

1.3 Participatory Science

Participatory science shares similarities with citizen science, community science, and public science in that it involves community members in various aspects of a research project, with the overall aim of achieving research objectives collaboratively. These terms are closely related, although community science often centers on the needs and priorities of the local community through collaborative development of solutions that directly benefit the people involved (Wandersman, 2003). We will be using participatory science as our terminology throughout this paper. Participatory-generated, authentic datasets are inherently messy, providing students with an opportunity to develop data literacy skills. These datasets also extend upon place-based education by integrating experiential learning and incorporating locally relevant data, all while learning about climate change. Participatory datasets are local to students when the data was collected within their direct community or ecosystem, or within their proximal, surrounding area. Through climate change curricula that incorporate data literacy and participatory science, controversy is averted and students have a higher potential to be environmentally engaged (Bhargava et al., 2015; Muccione et al., 2025; Smith et al., 2024; Williams et al., 2021; Zhang et al., 2023).

2 THEORETICAL FRAMING

To understand what motivated the student participants in our study to be engaged in pro-environmental activities we designed our study using Situated Expectancy Value Theory (SEVT). SEVT was developed to measure secondary school students' motivation to engage in a task, making it relevant for our study (Aschbacher et al., 2014; Eccles & Wigfield, 2024; Gaspard et al., 2017). SEVT constructs are tightly intertwined and dynamic in nature, which is important because early adolescents' values are developing and not fixed (Vecchione et al., 2020). According to SEVT, an individual's personal and environmental context, expectations to succeed, and subjective task-values predict their motivation (Eccles & Wigfield, 2020) (Figure 2.1). The context-dependent nature of motivation is shaped by an individual's sociocultural background, self-concept, and current environmental context. Moreover, how one values the utility of a task and attainment are both related to an individual's future goals, which youth are discovering during their schooling (Eccles, 2005). Using SEVT as a framework requires an exploration of how expectations of success and subjective task-values collectively shape motivations to complete a task within a specific context or environment.

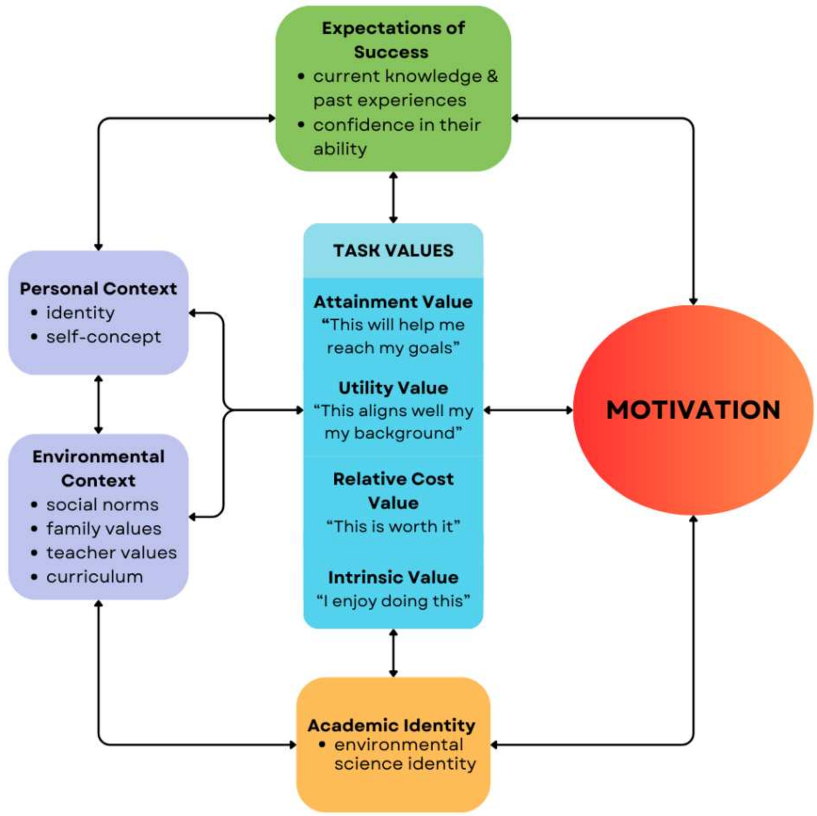

Figure 2.1. Situated Expectancy Value Theory model. Interrelated relationships of SEVT that flow into motivation. Purple are the external factors that the individual brings into the context. The green box represents expectations of success, blue represents task-values of environmental science, orange represents environmental science identity, and red represents the motivation that all the previous factors can affect.

Expectations of Success are defined as the individual's beliefs and confidence in their ability to complete a task. This may include performance in class activities. Expectancies are shaped by the individual's personal and environmental contexts through their experiences (Eccles & Wigfield, 2020; Wigfield & Eccles, 2000). Personal context includes an individual's self-concept and the sociocultural intersection that defines their identity, while environmental context includes their community context, family values, teacher's values, classroom or school social norms, as well as the curriculum being taught.

Subjective task-values refer to the personal worth individuals assign to a task, influencing their decision to engage in or complete it, and can be influenced by expectations of success, and personal and environmental context. These are dependent on the individual's personal and environmental context background and include attainment values, utility values, relative cost values, and intrinsic values (Eccles & Wigfield, 2020; Wigfield & Eccles, 2000). Utility values are tasks that an individual finds useful in helping them reach future goals. Intrinsic values are tasks that an individual enjoys. Cost values are tasks that the individual views as too emotionally or cognitively taxing, or, on the flip side, worth the effort (Flake et al., 2015; Perez et al., 2014). Attainment values describe how a task aligns with one's identity (Eccles, 2009); although, identity may also be considered an outcome of attainment values.

3 METHODS

To measure student motivation and environmental context, we used a mixed method, sequential explanatory approach starting with survey data and followed by teacher interviews and observations to explain survey results (Creswell et al, 2003). Students completed pre and post surveys before and after implementation of a pollinator phenology module designed to be completed over a week.

3.1 Pollinator phenology intervention

We created a climate change module that was framed around pollinator-plant phenology and participatory science data (Maksymkiw & Balgopal, *in review*). The module was designed to align with the Colorado academic standards for high school and middle school students which are built from the U.S. Next Generation Science Standards (NGSS Lead States, 2013). Three teachers piloted the module and provided feedback that we integrated into the materials. Teachers had the option of selecting and modifying lessons to suit their students' needs and interests.

The module begins with an introduction of participatory science and how students can get involved in a project within their local community. One lesson option was to learn what it is like to be a participatory scientist and collect data through a participatory science platform – iNaturalist. Students can engage with the pollinator-plant phenology content through discussions about seasonality and how climate change is affecting essential ecosystem interactions. They can explore an interactive mapping tool on the USA Phenological Network Database to visualize whether plant life and bumble bees are being affected by changing seasons over time. After students consider how pollinators can be affected by climate change, they design their own phenology studies using the existing dataset. The dataset includes phenology data on flowering and bumble bee occurrence timing from 1974-2023 in Colorado, as well as abiotic climate data on snowpack and temperature. Students construct their own hypotheses that can be tested using the provided data sets. The middle school students are provided graphs to interpret. As a final assessment, teachers have the choice for students to create a scientific poster or a written report describing their findings that they can share with their classmates.

3.2 Participants and context

We recruited secondary teachers with purposive sampling in the northern part of the state. Five teachers implemented the module. We collected 261 pre surveys and 224 post surveys of both middle and high school students. We had 126 matching pre and post surveys and within that we received 118 consent and assent forms. There were three additional populations that we did not include because the final sizes were too small to be treated as independent populations (<10). The final sample included two middle schools, which represented two distinct communities -- one in a suburban community (n=56) and one in a rural mountain community (n=42). Two veteran teachers --one in a suburban community teaching 8th grade students (n=56) and one in a rural mountain community teaching 7th grade students (n=42) – volunteered to help us collect data. Both teachers have been teaching between 12-15 years, primarily at the middle school level. The rural teacher has a degree in biology and grew up in a rural community in the state, while the suburban teacher has a degree in natural resource management and grew up in a mid-sized city in the Great Plains. Both teachers grew up spending time in natural areas. Students who took the pre-survey and the post-survey submitted their consent and assent forms, and attached their student ID number to both surveys were included in the sample.

The rural mountain school is situated directly in the mountains and sits just below a subalpine ecosystem. The economy is driven by education, service industries, and retail (Data USA, 2023). The suburban school is in a mid-sized city in the front range of the mountains and an hour away from the state capital. The suburban community is surrounded by county natural areas and is a 40-minute drive to the Mountains. Major employers in the community include a large state university, science and technical services, and healthcare (Data USA, 2023).

Participants were aged 12-15 across the two schools. The participants from the suburban school were more ethnically diverse compared to those from the rural school. In the suburban school, most participants were white (52%), while 28% were Hispanic, 7% were African American, and 11% identified as mixed ethnicity/race, and 2% did not provide a response. Participants identified as female (52%), male (46%), and or did not provide a response (2%). In the rural school, most participants were white (88%), while 5% were Hispanic, and 7% identified as mixed ethnicity/race. Rural participants identified as female (48%), male (40%), nonbinary (2%), and 10% did not provide a response.

3.3 Data Collection

This study was approved by the university ethics review board (#1904), as well as both participating school districts. We collected three types of data for this study: pre/post surveys, observations, and teacher interviews, which are described below.

Surveys. To assess students' motivation to engage in environmental issues, two surveys (which included eight demographic questions) were administered before and after the module was implemented (Supplementary Materials). The first part of the survey was from the Climate Change Attitude Survey (CCAS; Christensen & Knezek, 2015) and was developed from the Theory of Planned Behavior (Ajzen, 1985). This survey consists of 15 Likert-scale questions on a scale of 1-5. The survey measures student beliefs and intentions about making positive, pro-environmental changes, specifically mitigating climate change. The second part of the survey was modified from Aghekyan's (2019) Science Identities, Expectations of Success in Science, Values of Science, and Environmental Attitudes Survey, also referred to as SIEVEA. The SIEVEA survey was developed with Expectancy Value Theory (Wigfield & Eccles, 2000), science identities (Carlone & Johnson, 2007), and environmental attitudes (Dunlap et al., 2000). The survey consists of 14 Likert-scale questions on a scale from 1-5. SIEVEA identifies constructs that are important in underlying motivation to continued environmental science learning and application to their future lives. The constructs consist of expectations of success, environmental values, science identity, and environmental attitudes. Environmental attitudes are defined as motivations and highlighted any environmental actions students took within the survey (Aghekyan, 2019). We slightly modified questions to be focused on participatory science (Wigfield & Eccles, 2000). SIEVEA identifies environmental attitudes as motivations, so, we coded those questions as such (Aghekyan, 2019). With debate about where identity fits into SEVT (Eccles & Wigfield, 2024), this survey assumes that science identity is a separate construct and is also a predictor of motivation (Eccles, 2009).

Observational notes and interviews. For each class that implemented the module, observation notes, or informal interview data were collected to identify 1) how the teacher implemented the module and 2) how students responded to material. Although the curriculum was the same across the two contexts, the teachers may have implemented it differently and may have brought in their own biases. Hence, we conducted *semi-structured interviews* of both teachers to identify their existing environmental science motivations. Our interview protocol was informed by a published interview instrument about science teachers' pedagogical and environmental values (Conlon et al., 2025). We added questions about teachers' perceptions of community environmental values questions (Supplemental Materials). Interviews were approximately 90 minutes each and were conducted and transcribed by the first author.

3.4 Analysis

Student surveys. To analyze changes in responses on pre and post surveys for both student populations, we used a linear-mixed effects model (LME) for each SEVT construct (expectations of success, environmental science task-values, environmental science identity, and environmental science motivation). The R packages "lme4" and "lmerTest" were used to construct the models and determine significance (Bates et al., 2015; Kuznetsova et al., 2017). An LME is useful for this study because it accommodates unbalanced, missing data for students that did not complete all questions of the surveys. All pre and post survey data were grouped into SEVT constructs measured by the survey and summarized into mean suburban and rural population scores (see Supplementary Materials for descriptive statistics). After normality assumptions were met (constant variance of residuals and normal distribution), each construct was fit into the model.

Motivation, expectations of success, values, and environmental science identity were all predicted through the explanatory variables time (pre and post), locale (suburban and rural), and the interaction of time and locale. Initially, a random, class section variable was nested within each locale although we anticipated low variance. Locale and time are the fixed effects, and the subject is the random intercept to account for repeated measures of the same subject. To calculate the overall significance of variance within the fixed effects (locale and time), we used factorial analysis to understand the importance of each factor on each construct. After models were completed, follow-up pairwise comparison was completed with estimated marginal means from the models with the "emmeans" R package (Lenth, 2015). We performed two versions of contrast testing – one that measured the effect of time (pre to post) at each locale, and one that measured the effect of locale (rural or suburban) at each time point. Lastly, we calculated coefficients of variation to understand distributional changes within groups from pre to post survey.

Teacher contextual data. To better describe the environmental context of each population, including teacher motivation for community engaged activities, teacher surveys scores of the climate change attitudes survey were compared and triangulated with qualitative analysis of interview data. Subsequently, deductive coding informed by the SEVT constructs was completed for each teacher interview transcripts (210 minutes) (Aghekyan, 2019). Only narratives relevant to environmental science or the environment were coded. All coding was conducted using the qualitative data analysis software, MaxQDA. Both semantic (direct statements) and latent (inferred statements) thematic analysis were conducted (Braun & Clarke, 2019). We compared observation data of each module implementation to establish any similarities or differences within each classroom to determine if this could explain any potentially different student outcomes.

We established the trustworthiness of the analytic process through regular peer debriefing, inter-rating coding, and the use of member checking (Lincoln & Guba, 1985). Two coders reviewed and initially co-coded 10% of the transcripts, followed by independent coding. Initial inter-rater reliability resulted in 'nearly perfect' agreement of 87% and then through peer debriefing reached complete agreement of the codebook (see Supplemental Materials) (Landis & Koch, 1977). The themes that emerged from the teacher interviews helped us explain the results of the student surveys.

4 Results

We found that the intervention had different impacts on students from suburban and rural areas in three ways. First, suburban students showed increased environmental science identity after the module, resulting in a significant post-intervention gap between groups, with suburban students reporting higher identity scores than their rural peers. Second, rural students' environmental values declined following the intervention, creating a gap between them and suburban students, who maintained higher values. Third, rural students' motivations to be engaged in environmental issues was lower than suburban students and then decreased after the intervention, widening the margin. The variance between class sections was zero, so it was not included in the model. Modules were implemented similarly, and teacher survey scores were similar as well. While both teachers expressed high environmental science identities and motivations, their expectations for success differed slightly within their experiences, agency, and knowledge types.

4.1 Student Survey Results

Environmental Science Identity. Locale ($F(96.52) = 5.0558$, $P=0.02682$) and the interaction between locale and time ($F(93.57) = 4.296$, $P=0.04095$) had a significant effect on environmental science identity (Table 2.1). By following up with contrasts between time of survey and locales, suburban students had significantly higher environmental science identity scores by the end of the intervention with an estimated mean increase of 0.327 points ($t_{91.6}$= 2.806, P=0.0061) (Table 2.2; Figure 2.2). The coefficient of variation increased from 0.276 in the pre survey to 0.306 in the post survey. The suburban students started with a higher frequency of students who answered 'unsure' (Likert-scale 3) about their environmental science identity, but by the post survey the number of students who were unsure decreased and showed frequencies that skewed right into agreement (Likert-scale 4 and 5) with environmental science identity (Supplemental Materials). Rural students did not have a change in mean environmental science identity after the intervention (Table 2.2). However, after the intervention, students in rural and suburban populations became significantly divided in their responses with rural student responses being -0.533 points lower than suburban students (t_{153}=-2.988, P=0.0033) (Table 2.2; Figure 2.2).

Table 2.1. Linear mixed-effects factorial results of the SEVT and CCAS constructs. The locale is the suburban or rural school. The time is the time of survey, pre or post. ***P < 0.001 **P< 0.01 *P< 0.05.

SEVT construct	Fixed effects	Den DF	*F* value	*p* value
Environmental Science Identity	Locale	96.52	5.0558	0.02682*
	Time	93.57	2.409	0.12399
	Locale:Time	93.57	4.296	0.04095*
Environmental Science Values	Locale	96.67	4.899	0.02923*
	Time	92.99	1.347	0.24884
	Locale:Time	92.99	4.738	0.03203*
Expectations of Success in Environmental Science	Locale	97.10	0.8405	0.3615
	Time	93.72	1.0055	0.3186
	Locale:Time	93.72	2.677	0.1052
Environmental Science Motivation	Locale	94.63	16.28	0.0001108 ***

	Time	90.76	0.1336	0.7156
	Locale:Time	90.76	3.0275	0.08525
Don't believe, no need to try	Locale	96.30	2.412	0.1237
	Time	95.60	0.5114	0.4763
	Locale:Time	95.60	2.302	0.1325
'I can't change anything'	Locale	95.28	0.0895	0.7654
	Time	94.44	2.6466	0.1071
	Locale:Time	94.44	2.5676	0.1124

Table 2.2. Pairwise comparisons of each SEVT and CCAS construct within each locale (suburban or rural) and time (pre or posttest) contrasts from the LMM. ***$P < 0.001$ **$P < 0.01$ *$P < 0.05$.

SEVT construct	Contrast	Estimated mean difference	SE	df	t ratio	*p* value
Environmental Science Identity	Rural (post-pre)	-0.047	0.138	93.9	-0.341	0.7341
	Suburban (post-pre)	0.327	0.117	91.6	2.806	0.0061**
	Pre (rural-suburban)	-0.159	0.178	153	-0.889	0.3752
	Post (rural-suburban)	-0.533	0.178	153	-2.988	0.0033**
Environmental Science Values	Rural (post-pre)	-0.249	0.1140	93.1	-2.183	0.0316*
	Suburban (post-pre)	0.0759	0.0978	91.2	1.065	0.2895
	Pre (rural-suburban)	-0.172	0.169	139	-1.018	0.3103
	Post (rural-suburban)	-0.497	0.169	139	-2.949	0.0037**
Environmental Science Motivation	Rural (post-pre)	-0.160	0.1160	92.9	-1.377	0.1719
	Suburban (post-pre)	0.104	0.104	91.1	0.0978	0.2895
	Pre (rural-suburban)	-0.520	0.179	135	-2.914	<0.0001***

	Post (rural-suburban)	-0.784	0.179	135	-4.391	0.0042**
Don't believe, no need to try	Rural (post-pre)	0.2381	0.160	94.2	1.484	0.1410
	Suburban (post-pre)	-0.0856	0.141	95.7	-0.608	0.5444
	Pre (rural-suburban)	0.0766	0.187	170	0.410	0.6824
	Post (rural-suburban)	0.4003	0.187	170	2.141	0.0337*
'I can't change anything'	Rural (post-pre)	0.30159	0.140	94.2	2.148	0.0343*
	Suburban (post-pre)	0.00228	0.123	95.6	0.019	0.9853
	Pre (rural-suburban)	0.194	0.174	162	1.113	0.2672
	Post (rural-suburban)	0.194	0.174	162	1.113	0.2672

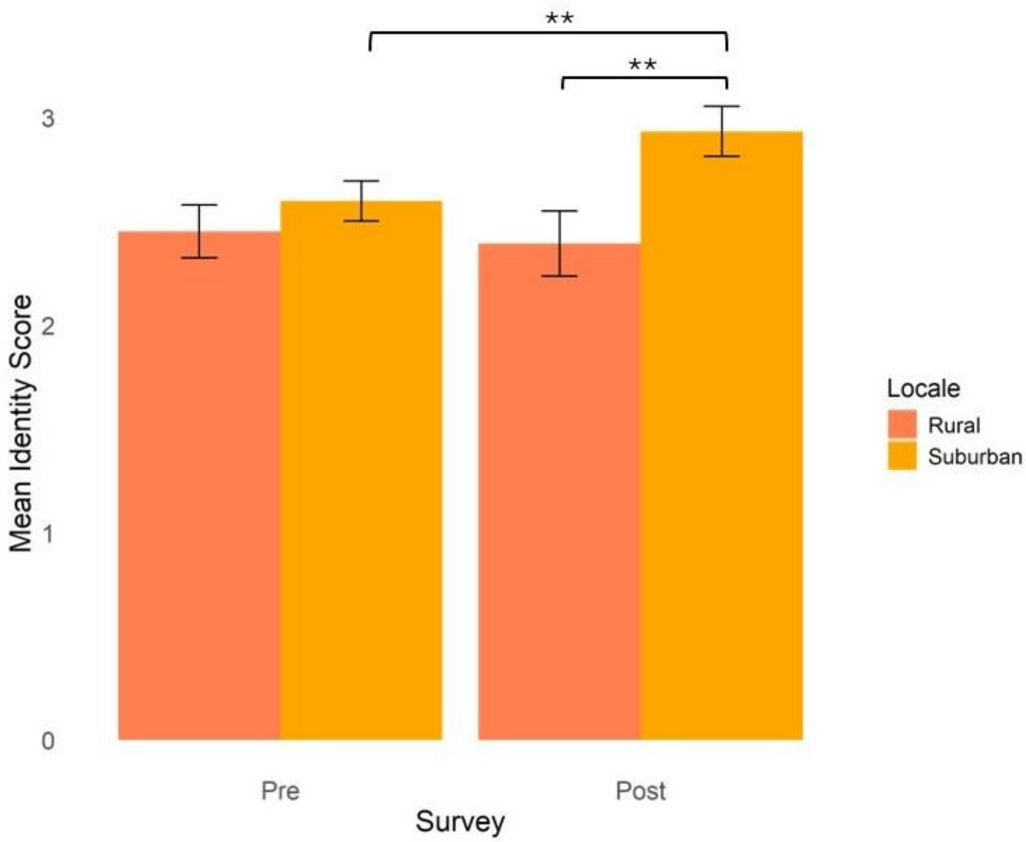

Figure 2.2. Mean environmental science identity of rural and suburban middle school students on pre and post survey responses. Error bars represent the standard error of the means. Asterisks indicate significant differences (** P<0.01).

Environmental Science Values. Locale (F(96.67)=4.899, P<0.02923) and the interaction of locale and time (F(92.99)=4.738, P=0.03230) had the most significant effect on environmental science values (Table 2.1). Time and locale were further assessed with contrasts of the estimated means. Rural students demonstrated a significant decrease of -0.2493 points in their mean environmental science values after the implementation of the module ($t_{93.1}$=-2.183, P=0.0316) (Table 2.2; Figure 2.3). The coefficient of variation increased in the pre survey from 0.297 to 0.357 in the post survey. The rural students started off with a higher frequency of students who were 'unsure' (Likert-scale 3) about their environmental science values, but by the post survey the frequency of students who answered 'unsure' decreased and results skewed left into disagreement (Likert-scale 1 and 2) with environmental science values (Supplemental Materials). Although, there was no change in suburban students' environmental science values after the intervention (Table 2.2). This caused the suburban and rural students to significantly split from one another on the post survey with rural students averaging -0.497 points less in environmental science values scores than suburban students (t_{139}=-2.949, P=0.0037) (Table 2.2; Figure 2.3).

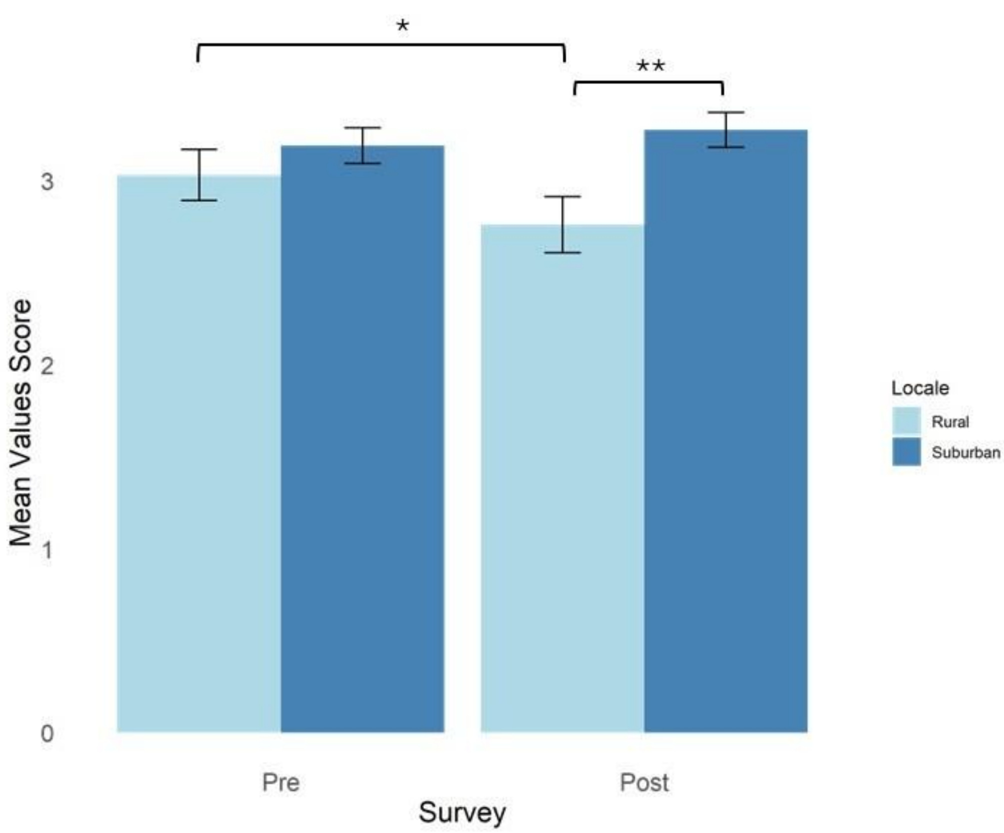

Figure 2.3. Mean environmental science values scores of pre and post surveys of rural and suburban middle school students. Error bars represent standard error of the means. Asterisks indicate significant differences (*P<0.05, **P<0.01).

Expectations of Success in Environmental Science. For rural and suburban students, the F-test showed no significance to locale, time, or the interaction of time (Table 2.1). Within the follow-up contrasts there was no significance as well (Table 2.2).

Environmental Science Motivation. Locale had a significant overall effect on motivation (F(94. 63)=16.28, P=0.0001108) (Table 2.1). Rural students had a significantly lower estimated mean motivation of -0.510 points before the intervention than suburban students (t_{135}=-2.914, P=0.0042) (Table 2.2; Figure 2.4). Rural student motivation became even lower than suburban students in the post survey with a mean estimated difference of -0.784 lower (t_{135}=-4.391, P<0.0001) (Table 2.2; Figure 2.4).

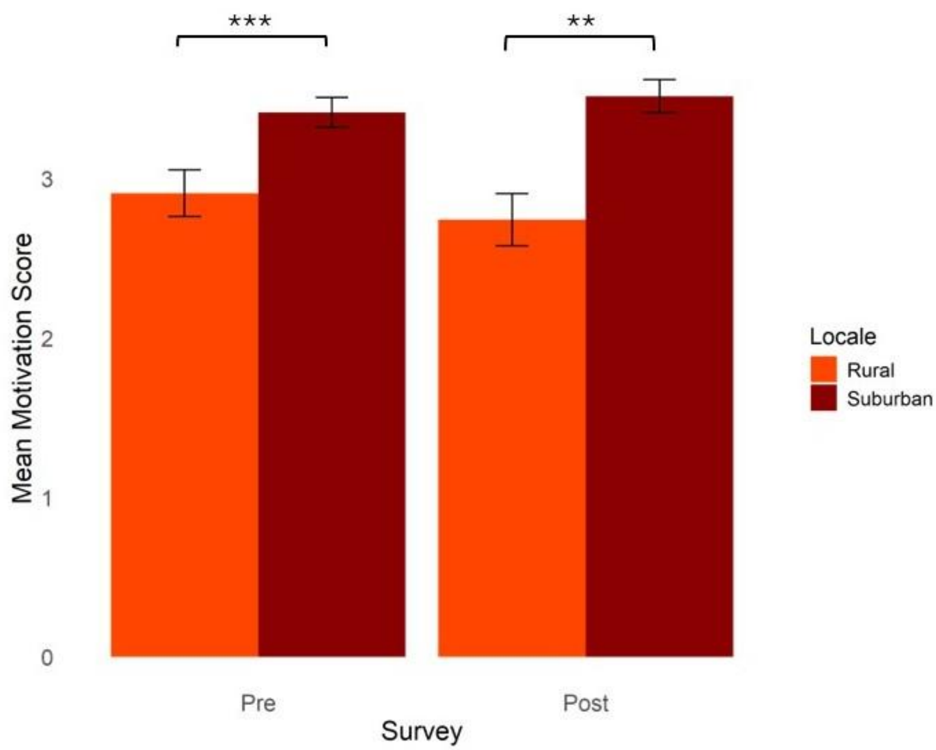

Figure 2.4. Mean environmental science motivation pre and post survey scores of rural and suburban middle school students. Error bars represent the standard error of the means. Asterisks indicate significant differences. (**P<0.01, ***P<0.001)

In the CCAS survey, the F-test showed no overall significance with the “Don’t believe, not need to try” construct on locale, indicating that the effect of locale was dependent on the pre or post survey time (Table 2.1). However, the contrasts between rural and suburban populations showed that the rural students had a significantly higher mean post survey response than suburban students (t_{170}=2.141, P=0.0337) (Table 2.2). In the development of this survey, Christensen & Knezek (2015) established that if participants responded on the agree side of the Likert scale, these items fell into the category of low personal relevance and low likelihood to act on climate change issues. Furthermore, the ‘I can’t change anything’ construct was significantly higher in rural students’ post survey than it was in their pre survey ($t_{94.2}$=2.148, P=0.0343) (Table 2.2). The overall effect of time was not significant (Table 2.1), so this result was dependent on locale -- specifically rural locale. These questions were associated with high psychological closeness with the subject and low efficacy (Christensen & Knezek, 2015). Because the rural students’ scores increased in this category and were higher in comparison to suburban students, we can predict a trend toward lowered motivation in comparison to suburban students. Since ‘don’t believe, no need to try’ and ‘I can’t change anything’ were associated with action, we triangulated these results from the SIEVEA survey to further establish lowered motivation in rural students after the module. No other survey items in the CCAS showed statistical significance (Supplemental Materials).

4.2 Teacher identities, values, expectations, and motivations

Both teachers exhibited very positive and motivated climate change attitudes, indicating a strong commitment to addressing climate change. While both teachers aligned on most questions, they showed some disagreement on questions related to the promise of individual and collective action to solve environmental issues. The suburban teacher believed that global climate change cannot be stopped and that there is not much he can do to solve environmental problems; however, the rural teacher answered oppositely. Both teachers were unsure if “the actions of individuals can make a positive difference in global climate change.” Although the answers differed, it may be that one teacher felt that each individual can make changes, and the other felt that it must be a collective that does so.

4.2.1 Module implementation

Both teachers modified the teaching materials for their students' needs. The suburban teacher spent 5 days teaching the module and the rural teacher spent 6 days teaching the module. The teachers used various combinations of our materials word-for-word and modified them for their own students. However, both teachers covered all main topics: participatory science, pollinator-plant phenology and climate change, and had students design their own study -- with varying emphasis on different topics. In addition, both teachers covered the same topics, stereotypes of scientists, participatory science projects conducted by local peers, and finding local participatory science projects in which they could get involved. One difference was how the teachers implemented the iNaturalist activity. The rural teacher did not have technology that allowed students to take photos to upload to the participatory science app, while the suburban teacher did and students were instructed to take photos and upload observations to iNatualist. Although the rural students have district-issued Chromebooks, they could not use these to take photos, and they have a no-phone policy at their school. However, the students had recently engaged in a biodiversity calculation activity the week before, so the teacher felt that our module was a natural follow-up to the inquiry activities he had just led.

The teachers, especially the suburban teacher, addressed environmental science identity. For example, the suburban teacher led a "draw a scientist" activity where groups of students each drew their idea of what a scientist looked like, what kind of work they did, and three adjectives to describe their scientist. The teacher used this activity as a segue to diminish any stereotypical thoughts they had about who a scientist could be. At the beginning of the following class period, the teacher reminded them that they are all scientists and can engage in scientific tasks.

The teachers differed in the way they approached the phenology material. Both teachers went through the same topics, although the rural teacher recounts their students easily grasping the pollinator-plant connection to the social-ecological system because they could connect it to the current lives of their families, friends, and neighbors.

> "*And because a lot of them, like, live on ranches and that's a reality for them, that was pretty easy connection to make … the kids are friends with that family [that has honeybee colonies], and they've visited it. So, it's a lot more like tangible to them."*

The rural teacher then asked students to think beyond their local community. *"And then I think the part that they don't normally think about is the broader impacts beyond us. How does this affect the food availability eastern half of the US, where they're relying on some of this."* The suburban students were able to make connections from pollinator-plant relationships to the social-ecological system but needed a reminder first about what a pollinator was. Although, they quickly made the connection between food crops and pollinators.

Both teachers used performance to help students make sense of phenology. The rural teacher acted out a scenario with his students:

> "*I pretended to be a honeybee. They buzzed around the room, and they all laughed, and I'm being silly. I've got nothing to do! There's no, there's no flowers! And then I would tell a kid to stand up. Be like, all right, you're gonna be the first flowering plant…stand up when I wink at ya. I buzz over and be all happy and be like, Well, there's only one, only one. That's all I got…And the kids really got into that.*"

However, for the online phenology mapping activity, both teachers struggled to get students to understand the interactive tool and interpret the maps. Map reading was a competency that both rural and suburban students had not yet mastered. However, with some modeling, the students "*definitely were more successful than I thought they would be at manipulating the filters and all that. Yeah, and for the most part did really well*.," the rural teacher explained. This was not surprising to the rural teacher, who asks his students to discuss a graph of the week. *"Every* *single Monday we come in, and I give them some graphs. We have to use it as a discussion point. They have to analyze it and draw a conclusion from it."*

Both teachers used guiding questions from the teaching materials and outlined what a hypothesis is and how it is constructed. The rural teacher asked students to design their own projects and create a poster to show their results, and the suburban teacher asked his students to create their own hypothesis and test them using graphical data. Suburban students were surprised when one of the graphs did not show a clear increase or decrease in phenological timing. While the suburban teacher highlighted that many students "were so over pollinators" after five days of learning about it, the rural teacher explained that students spent the most time on data analysis and drafting their argument. "*I was real rough on them, and kept having them go back on this piece, to make sure their rough draft was what I was expecting out of them before I gave them the green light to go on the poster.*" The rural students' final projects were graded as a summative assessment of the module. Neither group of students engaged in the peer review portion of the module.

4.2.2 Teacher contextual background

Both teachers described a strong connection to the environment and subsequently had high motivations to engage in environmental action, environmental values, and environmental identities. They both drew on their personal and professional experiences. The suburban teacher had been a backpacking guide, takes students on outdoor adventures, and spends a lot of their free time enjoying nature in whatever ways he can. As a teacher, he explained that "*Our school did trips through a program called copack."* And, in his personal time, he explained that he has "*gone hiking and backpacking have been… all over the United States. So, I've gotten to see a lot of different types of wildlife in their native habitat."* Likewise, the rural teacher spends a lot of time outdoors. However, he also spoke about his observations of how climate changes have shaped the environment. "*And we'd take breaks during the pandemic, and we would go outside and sit on the football field, on tables out there, watching the wildfire. That was very dystopian*." He also recalled that before the pandemic, there was a destructive fire in his community, "*…which was devastating, took the entire county burned down. We got evacuated."* He continued to explain that "*... the wind picked up, and it ran like 40 miles an hour, and everyone was panicking to get out of [city]. It was running right towards the [city], friends and coworkers and students, like some of them, couldn't go home.*" The rural teacher explained that growing up with wildfires and being evacuated defined him as a person. For this reason, he makes an effort to understand and acknowledge local issues that matter to his students, even if they are not part of his personal experience. For instance, although he has never ranched or managed livestock, he is aware that some of his students come from ranching families and that topics like wolf reintroduction—controversial due to concerns about livestock predation—are relevant in their lives.

> "*there's a rancher that lives down the street who was shooting coyotes keep them off ranch, and he saw a wolf, and he called it into CPW, and he's like, Hey, there's a wolf on my property. I'm shooting coyotes. And they're like, it's not a wolf. It's like, yeah, pretty sure it's a wolf. They're like, nope. The wolves aren't in Colorado, and they shot it, walked up, sent a picture to them, and they're like, yep, that's a wolf. You're under arrest. And they fought for five years. He was supposed to spend five years in prison for shooting the wolf that the CPW officer office told them to shoot, and he ended up not having to serve time. But it was a five year battle. So you have stuff like that. Then the wolves get reintroduced… I mean, lose a cow, that's five grand minimum… The one pair of wolves had a litter this summer. They built a den on these people's property, and they're killing cattle, left and right and sheep.*"

This story is relevant, not because it is related to climate change, but because rural residents often feel that they are not in control of the regulations, laws, and policies that govern their lives and livelihoods. The rural teacher, without explicitly using the words, explained that rural communities and possibly students do not feel that they have control over how the environment is changing, nor how it is managed, despite depending on it for their security.

The suburban teacher, on the other hand, is very much aware of the impacts of climate change such as drought, but did not reference how it impacts his community or students directly. "*we've had droughts before and I'm kind of like Yeah, but they don't seem to end and they're not seeing an end to this one*." However, the rural teacher has many examples of the direct impact of climate change on the lives of his students and their families. For example, he explains that as winters are warming, and "*it's not going to interrupt the larval stage, and so all those eggs are going to be able to survive it. And so we're going to have an increase in this [beetle killed trees]."* Although beetle kill impacts on the spread of wildfire has been refuted in the Western United States (Hart et al., 2015), it reflects his concern with the chances of forest fires spreading quickly into his community, threatening the safety of rural residents in the mountains.

Both teachers shared that they do not expect to get challenged too often by students, although it can occur. The suburban teacher acknowledges that he does not have to confront parents and students as much as other districts do. *"And so, I don't get challenged by a lot of parents on anything like that, which I know in other schools, they do and they it's usually not worth the controversy to lose the relationship with the child over a single topic."* Even the rural teacher mentions that students do not challenge him; however, he explained that students will challenge one another. To avoid confrontations, the rural teacher said that he builds trust with his students, gauges prior knowledge, asks students to use data to support their arguments, and gets everyone to the same starting point before beginning a potentially controversial lesson. *"And there's always gonna be situations where kids or parents get mad, but I've had very few problems with that, probably count on one hand where I've had actual issues that escalated beyond a discussion with the student."*

Another commonality is that both teachers said that students often mimic the political positions of their parents or friends regarding climate change. The suburban teacher explained that *"they're like, oh, yeah, that's not even though I've heard this at home, or I've heard this on the news, or I heard it on Tiktok, okay, but follow it to its conclusion then."* Similarly, the rural teacher said he has *"parrot students, parroting their parents, they will, and I let them say whatever they want."* This may reflect a tendency among students at this age to be influenced by the views of people in their lives. Such influences could have shaped their survey responses and might offer some insight into the broader perspectives present within their communities.

The two teachers' expectations varied, especially regarding how to mitigate climate change. Overall, the suburban teacher felt that there is not enough environmental action happening.

> *"there's not a big enough sense of urgency with what's going on, because the perception is well, you know, I saw moose so you know, wildlife must be fine…I'm like …most of those are going to die out. They're just not going to exist anymore…in reality… their entire environment was destroyed"*

Even within his school, the suburban teacher described feeling frustrated. After the school committed to reducing their carbon footprint through a school-wide challenge, he felt like he was the only one trying to decrease energy usage at the school. "*Yeah, and nobody cared. … so they might do lip service to it, but not actually follow through with action*." He also lamented that the public wants to visit national parks, but people do not manage their own behaviors in caring for public spaces. *"when people went and tried to enjoy this, this gift of like, open public lands. They didn't bother to learn how to take care of it. And so, trash everywhere when the national parks closed down…"* The suburban teacher described feeling disappointed that his efforts to promote sustainable behaviors may be a moot point if others are not also engaged. "*It just is difficult to want to keep maintaining [sustainable actions] when it's kind of like, Oh, so you get to do that, but I have to sacrifice every day for my entire life.*" He also brought up feeling like he does not have a lot of hope even in some of the climate-smart options for sustainable living. It appears as if he does not trust the motives of companies claiming to have a sustainable framework.

> *"even though I know there's supposed to be things that you can offset your carbon usage, but I think a bunch of those are just a bunch of hooey that it's just people taking your money and making you feel good about yourself, because I haven't found one yet that I, yeah, truly believe they're actually, are you really planting 10 million trees a year? Because I would love to know where you're planting all of these 10 million trees, yeah, and who is planting them, and why is $28 enough to do that, right?"*

However, the teacher acknowledges that not everyone in his community may prioritize protecting earth's resources because of differences in socioeconomic standing.

> *"If changing over to an electric car, you can afford to do that. But if, if you are not in that place, both socio and economically, than to say, hey, you know you should always buy reusable …so what does environmental look like when it doesn't exclude those who can't afford it?"*

For different reasons, the rural teacher expressed frustrations, but as stated earlier, it is because he (and possibly his students) feels that their lives are controlled by the urban voters, who help enact laws that govern the lives of rural residents. *"it's done as kind of like a publicity stunt, almost voted for by people [in urban areas], but we're the ones that live with them in our backyard."* When discussing how laws impact his community, the rural teacher explained that: *"This is something that people have decided for us, and our voice and our concerns don't really* *matter, and we can't sway the electorate to view our points"* He perceives that when decisions are made for them, it instills a sense of powerlessness within the community's lives. Again, he uses the example of wolf reintroduction in rural areas. *"all the hipsters in [city], thought it'd be cool to have wolves in Colorado, but we can't pay rent now because the wolves are in Colorado. … I can see where that hopelessness would stem from on that particular topic."* When asked to connect powerlessness in the community to how students may feel about taking climate change action the teacher explained that community members, including students, do not feel hopeful because they feel non-agentic.

> *"…you feel helpless with the wildfire; you feel helpless with the wolf situation. You feel helpless with snowpack, and then you're more acutely aware of a very specific thing, like in your unit, day of first flowering plants is changing, and that's messing with the bees. They're suddenly like…this is another one. Like, it's more like piling on, then it is like motivating them to change it, because we've been powerless in these past situations and bringing up something new is like oh, [explicative]."*

For slightly different reasons, both teachers recognized their lack of agency to enact changes in their respective communities. The suburban teacher described people agreeing with the need for sustainability but not following up with sustainable actions. The rural teacher felt non-agentic because many policies and regulations that affect his community's livelihood are enacted into law by suburban and urban residents. Furthermore, both teachers expressed a lack of control to mitigate climate change at an individual level, even though they continue to teach about social ecological issues in their classes.

5 DISCUSSION

In this study, we sought to evaluate how two middle school student populations (rural and suburban) in one state engaged in a place-based module designed for students to learn about climate change and participatory science. Through comparison of students and their respective teachers' environmental science identities, values, and expectations, we concluded that their motivations to be environmentally engaged differed. Overall, our results showed that motivational outcomes differed across middle school suburban and rural student populations. Recognizing these differences is important for educators to understand how to frame environmental challenges in ways that support student motivation, particularly as climate change becomes a more tangible part of their everyday experiences. These results are also important to identify and understand contextual differences in how suburban and rural students learn and become environmentally motivated.

By the end of the module, suburban students had higher environmental science identity, and although it was not our intent, rural students had lower environmental science values than when they started. As a result, the gap between suburban and rural students' science identities increased over the study. Interestingly, the rural students had lower environmental science motivation before the module started and after the module ended. We believe that our findings are significant because the two teachers implemented the module in similar ways and also shared similarly high environmental science identities, values, and motivations. They both expressed frustrations with how communities manage environmental issues, yet they both continue to be engaged themselves and encourage their students to do so too. The main differences between the two teachers were within their experiences, knowledge types, and expectations for the future of climate change. These differences highlight the dichotomy of context between the two populations which is further explored in this section.

5.1 Environmental Science Identity

Suburban students had a higher affiliation with environmental science identity after the intervention. The inclusion of PBE through participatory science may have contributed to these results. Research indicates that for adults there is a trend towards an increased affiliation with a science identity after engaging in participatory science projects or training content (He et al., 2019; Merenlender et al., 2016) and once self-efficacy becomes obtained (Jackson et al., 2015). Working in teams of students on local environmental science projects about local, urban ecology can also lead to youth having a stronger sense of unity and social identity with each other, although these students also worked in collaboration with local stakeholders (Gallay et al., 2020). In a study of middle school girls, Phillips and colleagues (2024) reported that within the context of National Parks and varying involvement within participatory science projects, identity was positively impacted, although these results were found within an informal learning environment. Another study of ninth graders found positive attitude changes towards participatory science identity after engaging in authentic participatory projects that used mobile devices to identify and collect data (Wallace & Bodzin, 2017). The suburban students in our study used electronic devices to identify and collect data to practice being a field, participatory scientist as well. This may have contributed to our findings as well, although it should be further explored to determine if this variable was sufficient to explain the difference between the two populations of students we studied.

Not all participatory science interventions have impacts on students' identities, as we found with our rural student population. In one study that focused on secondary students, researchers found that after a two-month participatory project on hummingbird populations where students collected and uploaded data to a participatory platform, students' identity was not affected (Williams et al., 2021). Suburban students in our study engaged with the material for only five days, suggesting that differences in outcomes may be influenced by the type of intervention—particularly the agency in the direction of their projects (Verhoeven et al., 2021)—or that the results are context-dependent, warranting further investigation.

Other aspects that are known to impact youth science identity in environmental curricula are working on environmental projects that are locally relevant (Gallay et al., 2021). This is possibly due to the personal connection they form to the topic which aids in identity formation (Blatt, 2014). This is like our study where students were focused on local pollinator and plant phenology. Gallay and colleagues (2021) suggested that the contribution of that knowledge to their local communities from local projects students work on can be attributed to environmental identity which may have been the case for the suburban students as well. In our study, the rural students had an even closer connection to the misalignment of pollinator and plant phenology. However, although both populations demonstrated content understanding, the module only seemed to have an effect on suburban students' identity.

When participatory projects provide an opportunity for decision-making there is a higher chance of students developing a science identity – especially when they have already engaged in participatory science in the past (Huffling, 2015). Since we did not survey whether students have participated in similar projects prior to this experience, this may be important for future studies to consider. Additionally, the decision students made were through data interpretation versus an actionable environmental decision. The students were agentic in designing their own research question, although it was within the confines of limited bumble bees, flowers, and their phenological timing. Furthermore, situating students to view themselves as agents of change and being able to see the visible levels of potential change is important for identity formation (Tierney et al., 2020). Through the discussion of pollinator phenology impacts to their local community and the broader social-ecological system, students had a chance to visualize the different scales at which the project had importance, although again, they had no direct role in the action that takes place after. Including a more explicit decision process with more freedom in designing a project for students in PBE may have more of an impact on identity in future research.

Despite experiencing similar curricular content, rural students did not demonstrate the same identity gains as their suburban peers. This suggests that while the discussed curricular features may have supported the suburban students' science identity in this study, the broader sociocultural context in which students engage with the material likely plays a role in shaping identity outcomes. For example, not providing a clear decision-making aspect where there was potential for actionable change may not have influenced suburban students, although possibly this influenced rural students because of their community context.

5.2 Environmental Science Values

Rural students' environmental values decreased in the posttest. Environmental values literature in the context of youth and rural students is still developing, with rural regions being less described. Although outside of the US, a study exploring how values, interest, and attitudes influence environmental concern, rural secondary students had lower interest in these topics compared to students in suburban and other densely populated regions (Uitto et al., 2011). They define personal interest as a state of direction towards enjoyment in the subject. Within the context of SEVT interest can be described as an intrinsic value (Eccles & Wigfield, 2020; Schiefele, 1991). This reflects a pattern of lower environmental interest values among rural students compared to their suburban and urban peers. While our survey included items related to intrinsic value, the observed decrease may reflect declining interest in the subject. However, the absence of cost and utility value survey items limits our ability to fully interpret this shift, presenting a caveat in the survey.

Another possible explanation for this is due to insufficient reference to action that can be taken to improve pollinator decline in their direct community. Although participatory science was suggested as a solution, perhaps there was not a direct association with this as positively impacting their community. In a study of rural middle school students in the Midwest, focused on connecting students with the "environmental commons" (including what the community values), students engaged with a PBE stewardship project and found that students most valued the environmental stewardship actions they took because of the positive impact it had on their communities and ecosystem around them (Gallay et al., 2016). This can be interpreted as an attainment value due to the personal relevance of their home (Eccles & Wigfield, 2020). Therefore, if students can observe the benefits that a participatory project has on the wellbeing of their community, they may be more inclined to engage in it, leading to higher values.

The main difference in our intervention compared to Galley and colleague's (2016) was their project foregrounded direct solutions. When the rural students were finished with their posters, the teacher ran out of time to have students present the results. Perhaps presenting results to local officials or applying their findings to their local ecosystem through restoration may have increased their sense of values (as well as their agency to affect change). This also may highlight how PBE in suburban places in absence of action-oriented solutions may be sufficient, but in rural communities, students may need to address direct impacts and solutions that students can see and feel motivated in which to engage. This is consistent with Azano (2011) who pointed to critical PBE pedagogy as a way for rural students to discuss how issues directly relate to their community and to increase confidence in being agents of change. Likewise, Zimmerman &

Weible (2017) call on teachers to consider how rural high school students can engage in collective action.

Because of action-oriented factors coming up in both identity and values constructs, this may reflect different mindsets of students in our study. Suburban students appear more focused on the broader solutions of participatory science to their community, while rural students are more focused on the immediate solutions of participatory science to their community. This proposed way of thinking is reflective within the rural students' CCAS survey questions because after the module they showed personal connection to solving environmental issues, although also associated with lower agency. Our participants' values likely reflect those of their parents, as others have found. Lithuanian students' values were found to be in alignment with their parents or guardians (Balundė & Perlaviciute, 2023). Furthermore, youth values can reflect social groups, Benish-Weisman and colleagues (2022) found for Israeli youth. Although these studies were conducted in Lithuania and Isreal, they highlight how communities can be shaped by peer and familial interactions. This further suggests that our values and identity findings may reflect the differing broad and immediate mindsets similarly throughout each independent suburban and rural community social circle.

5.3 Environmental Science Motivation

Values and identity explain people's pro-environmental behavior (Balundė et al., 2020; van der Werff et al., 2013a, 2013b). SEVT assumes the interconnectedness of identity, values, and motivation. Therefore, it is not surprising that since identity was higher in suburban students and values were lower in rural students, their motivational orientations are parallel to our findings following the module implementation – with rural students overall having lower motivation in comparison to suburban students. Changes in identity and values can explain changes in motivation, especially since authentic data were a part of the module (Ballard et al., 2017; Nasir et al., 2006). The use of an authentic participatory dataset engages youth in the 'real' scientific process which has been shown to increase motivation to learn science.

Rural students started and ended the module with lower motivation than suburban peers. This is consistent with Le and Kelly (2024) who investigated rural-urban differences in California adolescents – showing that rural students had lower civic engagement than their urban peers. Place has been shown to be important for adolescents as mediating environmental behavior (Ballard et al., 2017; Bartolo et al., 2023; Kudryavtsev et al., 2012; Vaske & and Kobrin, 2011). Additionally, the way people respond to "place" and what defines a person's "place" varies across contexts (Corbett, 2020). The way people relate to nature also differs across cultural environments (Milfont & Schultz, 2016). Furthermore, climate action can be mediated by social groups (Haslam et al., 1999), so it is important to look into these independent contexts.

Although teacher and community context does not clearly explain student motivations because it is not a direct measurement of students, it provides a possible explanation for our findings outside of the effect of the module. Schools function as part of an interconnected system, beginning at the individual classroom level and scope outward to the district level (Wright et al., 2023). Within the scope of the classroom the teachers taught the module similarly, with differences lying mainly in the extent of the project the students completed. However, the suburban students did not show a decrease in motivation so the lack of a project probably did not affect them in that way, highlighting how engagement in only pieces of the scientific process in participatory science does not jeopardize learning potential and can still influence environmental behavior in secondary students (Berndt & Nitz, 2023). On the contrary, rural students would have been expected to have increased motivation because they were engaged in developing their own projects. Consistent with our identity and values findings, since students did not present their findings, discuss them with the class or external stakeholders, or act on the problem in some other way, this can impact motivation as well (Ballard et al., 2017).

Both teachers shared several attributes – experience teaching, high environmental science identity and values, and high interests in motivating their students to care about environmental issues. The main differences were the two teachers' expectations for success. The rural teacher and suburban teacher referred to differing experiences and knowledge types throughout the interviews. The rural teacher emphasized local, lived experiences and community-based knowledge, whereas the suburban teacher tended to reference broader, more generalized knowledge extending beyond their immediate context. For instance, the rural teacher spoke in detail about the wildfires affecting his life inside and outside of teaching. This teacher believes that this was a defining event for their students and impacted the local community greatly – both financially and emotionally.

The rural teacher also highlighted how the community is heavily reliant on the environment for the security of their livelihood like most rural places around the world (Davis et al., 2010). This community is economically supported mainly through jobs in education, service industries, and retail (Data USA, 2023). The teacher noted that tourism plays a major role in sustaining the community, indirectly supporting jobs in food and retail. As such, environmental changes driven by climate change—such as altered tourism patterns—pose real threats to the local economy (Scott et al., 2012). Additionally, this school district connects ranching communities.

After a wolf-reintroduction into the local area, the teacher reflected on how it affected his community even though it did not affect him directly. He reported that this has been a high point of conversation in the area and expressed empathy for his community members. The teacher explained how wolf reintroduction has affected the economic stability of community members and demonstrated a deep understanding of the process that follows when a wolf kills livestock – pointing to his tight-knit connection to the community, even referencing it as a reflection of his identity. This is consistent with a study examining the differences in rural teacher-connectedness to their communities, with the veteran rural teachers as having an array of knowledge about past community experiences (Starrett et al., 2021). When the teacher and community are connected, it can result in educational settings becoming intertwined with the community experience (Howley et al., 2011) which may have influenced the rural student in our study.

The rural teacher also expressed a sense of limited control over environmental and economic forces affecting the community. This is aligned in the teacher survey results where the rural teacher had low agreement with solving environmental issues on an individual basis. This is consistent with other rural places where residents feel marginal and undervalued compared to larger populated areas (McKay et al., 2021; Walsh, 2012). Additionally, rural students responded similarly to their teachers on this part of the survey, further suggesting a shared mindset characterized by low self-efficacy despite a perceived closeness to the problem of environmental issues. This perceived lack of agency may mirror a broader community sentiment, which could have been internalized by students—either through direct messages from the teacher, community discourse, or personal experience. The teacher reported that in addition to the implication to wolf reintroduction, many students were directly affected by the wildfires, reinforcing the idea that environmental crises are not abstract for this group, but lived and recurring disruptions. He described this as piled-up powerlessness—a cumulative emotional toll from repeatedly witnessing their community harmed by uncontrollable environmental events.

This may reflect their lower motivation due to a feeling of powerlessness. In a study of rural adolescent who engaged with a unit about their local watershed and the environmental impacts, after it was over they felt like they were not sure how to make collective positive change to their lives with their new information (Zimmerman & Weible, 2017). Feelings of environmental powerlessness can translate to inaction when in association with 'real helplessness,' powerlessness that stems from external factors out of their control (Gunderson, 2023). Although these powerlessness findings did not show up in our quantitative survey results, this is a potential explanation for the initial lower motivation scores.

In contrast, the suburban teacher felt powerless in his inability to control the broader world in being environmentally conscious of their choices. This triangulates our teacher survey results – although small differences, the suburban teacher showed greater agreement with statements about broad environmental problems being unsolved compared to the rural teacher. This is consistent with a study that showed the climate-risk perception of people in urban cities have more concern about climate change impacting their general state of residence and the broader world relative to the immediate context of themselves, family, or their city (Sullivan & White, 2019). This type of powerlessness, because it is broader, may not affect the students because of the distant concern reflected in their higher motivation, although this warrants further investigation.

One way to counteract feelings of powerlessness among rural students is by integrating their livelihood experiences into PBE to foster a sense of agency and environmental motivation. Bruno and colleagues (2019) called for livelihoods implications to be incorporated into outreach and extension work with rural ranchers. While integrating livelihood into PBE is limited beyond incorporating relevant skills into PBE (Poole et al., 2013), we advocate for an earlier step: the recognition and inclusion of students' livelihood contexts within PBE curricula. This may involve skill-building but, more fundamentally, centers on validating the students' lived experiences. Although middle schoolers may be perceived as having less connection to livelihoods, adolescents who are deeply rooted within their rural communities tend to choose careers that allow them to remain and contribute locally to their community (Meece et al., 2014). At the same time, secondary students outside of a rural context have demonstrated the ability to critically evaluate expert information about environmental issues indicating an active intake of knowledge and openness to examining real world environmental problems (Jiménez-Aleixandre, 2002). Together, these findings suggest that adolescents have potential to engage thoughtfully with challenges affecting their communities, highlighting that youth may be receptive to environmental education centered around local livelihoods. Given that the rural students in our study likely shared similar perspectives through their community ties, learning about local livelihoods may hold particular relevance for them, as well as for other rural populations. Building on our earlier discussion of meaningful solutions for rural learners, incorporating local livelihoods—both in content through engagement with related challenges and most importantly, potential solutions—emerges as a direction for future exploration.

6 LIMITATIONS

Several limitations should be considered when interpreting and applying our findings. The teachers who agreed to participate in our study likely want climate change education in schools and integrate it into their course curriculum regularly. We likely did not capture the full range in teacher environmental values regarding reaching climate change in middle school science classrooms. Within the student participatory science vignettes on the website, these students were all suburban, so relation to those students could have been higher in the suburban population. Additionally, the SIEVEA survey was designed for high school students and not middle school students. This survey provided us with a mechanism to measure environmental science motivation, although our student results should be interpreted with caution. Our results are limited to the students of just a single teacher within each school. Within each class, our data were limited to students who completed both pre and post-surveys and who submitted both consent and assent forms. Lastly, we did not measure motivation beyond the end of the module so we cannot say for certain that motivation was shaped by their identity and values and if it did, whether it persisted.

7 CONCLUSION

This study extends our prior work by exploring how suburban and rural middle school students respond differently to a PBE, participatory science module on climate change. While the intervention supported environmental science identity development and motivation in suburban students, rural students demonstrated decreased environmental values and overall lower motivation before and after the module. Through the lens of SEVT, these differences reflect the influence of identity, values, and sociocultural context on motivation. For suburban students, working with authentic data, making connections to local pollinator issues, and using digital tools supported identity formation and likely motivation. However, for rural students, the absence of clear opportunities for action, community engagement, or decision-making may have limited the module's effectiveness in cultivating motivation and values.

Importantly, rural students' responses appeared influenced not only by the curriculum but also by broader community narratives of environmental vulnerability and powerlessness, as well as a strong sense of place and lived experience. These findings suggest that in rural contexts, PBE must include action-oriented outcomes that connect directly to students' livelihoods.

Tailoring participatory science experiences to reflect students' social and cultural contexts may be crucial in fostering motivation and empowering youth to engage meaningfully with climate change and environmental challenges.

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LESSON PLAN

Phenological Patterns in Pollinators & Plants

High school students

Duration: Up to 5 lessons; depending on the length of class periods, 5 lessons may take 4-7 days.

- Lesson 1: Participatory Science
- Lesson 2: Pollinator-Plant Phenology in response to Climate Change
- Lesson 3: Scientific Process and Creating Hypotheses
- Lesson 4: Constructing a Scientific Argument
- [Optional] Lesson 5: Presentation of Scientific Argument and Peer Evaluations

Materials: (All materials can be imported into Google Apps)

- Phenological Patterns Module Slides - HS (download as a copy to edit)
- HSNotecatcher Pollinator Phenology
- iNaturalist - Seek Activity
- Poster Assignment
- Phenology Data - Students (download as a copy for students to edit)
- Phenology Data - Faculty (reference with figures key)
- NPN Activity
- How to Create a Figure
- Peer Evaluation Form
- Projector or smartboard
- Class set of computers or tablets with internet access
- Downloaded App on electronic devices – Seek iNaturalist
- Class materials: students' science notebooks (e-notebooks or paper notebooks), poster boards (if posters are not done electronically), markers, etc.

Learning Objectives: Students will be able to

- Skills: [Demonstrate data literacy and scientific literacy]
    - Analyze data and graphical figures to identify patterns.
    - Create figures with different variables
    - Construct a scientific argument (using the C-E-R framework)
- Knowledge:
    - Explain how changing climate might affect animals, like bumblebees, flowering plants, and society.
    - Construct a short argumentative essay with a claim, evidence (from graphical figures), and reasoning about climate change impacts on plants and insects.

Teacher Preparation:

1. Upload the following Qualtrics links to your course page for students complete before and after the module (at the top of each survey it is labeled as pre and post). These links are also added as QR codes in the PowerPoint.
    a. Student pre-survey: Pre-Survey
    b. Student post-survey: Post-Survey
2. **Please complete the following *teacher* Qualtrics survey BEFORE you teach the module: BEFORE: Teacher CC Survey**
    a. **AFTER you are finished teaching the module, please complete the *teacher* Qualtrics survey: AFTER: Teacher Module Survey**
3. Review the slide deck if you would like to use it as a resource (Phenological Patterns Module Slides - HS)
4. Upload HSNotecatcher Pollinator Phenology to the course page and/or make print copies for all students. This document guides students through the module each day. At the end of this document are instructions for creating a poster draft. Depending on your availability the draft can be the final project, or they can create a final poster in PowerPoint/on paper and do a presentation.
5. Additionally review and upload the NPN Activity, Phenology Data - Students, How to Create a Figure, Poster Assignment, iNaturalist - Seek Activity, and Peer Evaluation Form to your course page and/or make print copies for students.
6. Upload the following websites to your course page: (USANPN: Where Did Spring Arrive Early This Year? and Participatory Science Website)
7. The iNaturalist Seek Activity can be done in class or a homework assignment. If doing it in class download the 'Seek' App onto classroom devices or instruct students to download the app and create an account onto their personal devices.
8. Add the following words to a word wall or memo pad:
    a. Participatory Science
    b. Phenology
    c. Phenophase
    d. Abiotic Variable
    e. Biotic Variable
    f. Frost Tolerance
    g. Social-Ecological System
    h. Hypothesis
    i. Predictions

    Extension terms:
    j. Phenological Mismatch
    k. Specialist and Generalist Species
9. This lesson is broken up into five 1-hour class periods, although depending on your availability and timing of class periods, **feel free to adjust it**.

Lesson Overview

Stage	Student Does	Teacher Does
Class Period 1: Introduction to Participatory Science (Engage)	**SUMBIT PRE-SURVEY** **Complete the online pre-survey individually. Pre-Survey** ENGAGE IN DISCUSSION Consider what it means to be a "scientist" and do science. Discussion questions: - *Do you know of any scientists?* - *How would you describe them?* - *Think of three adjectives you would use to describe a scientist.* WATCH VIDEO Watch short video on a cherry blossom phenology study in WA and think about how the data are being collected. Then, they will share out. They will record how the adjectives they chose previously compare to the people in the video. ENGAGE IN DISCUSSION Engage in discussion with the class to brainstorm what participatory science could mean. EXPLORE WEBSITE	**PROVIDE LINK OR QR CODE** **Start by instructing students to navigate to the pre-survey either with the QR code in the slides or through the link.** **Teachers: please remember to take the BEFORE: Teacher CC Survey**** LEAD DISCUSSION Facilitate a discussion about scientists and how we tend to think about them: *how do you become a scientist? Can anyone be a scientist?* PLAY VIDEO: Show students participatory cherry blossom phenology video within slide deck (#11). https://youtu.be/h-7YZcNJwhw Ask students to pay attention to the data collection portion. *Ask them who was doing the data collection?* LEAD DISCUSSION: Ask students what they think participatory science is (what does it mean to participate in something?) INTRODUCE WEBSITE Then, introduce **participatory science** by asking students to explore

	Explore the website with information on participatory science, vignettes, and projects. Students will write down what participatory science means in their note catcher [along with the other terms in the glossary tab if the teacher instructs them to do so]. Then, they should read the participatory science vignettes and brainstorm possible ways they can get involved in their local area. ACTIVITY (OR as homework) Students will use the downloaded iNaturalist Seek App and test out the role of being a participatory scientist. Students will record: 1) Three plants they identified 2) One other interesting organism	the following website: Participatory Science Website Instruct students to answer the questions in their note catcher and either copy down glossary terms from the website OR discuss the terms as a class as you go through the material (bolded terms in note catcher that corresponds to timing of lesson). LEAD ACTIVITY: (Option to make this a homework assignment) Now, students will try out collecting participatory science data in pairs. Direct students to identify plants and animals outside with their Seek Apps by using the iNaturalist - Seek Activity
Class Period 2: Pollinator-Plant Phenology in Response to Climate Change (Explore)	ENGAGE IN DISCUSSION Participate in a class discussion about the changing seasons. Possible discussion points: - *What causes seasons? (connect back to astronomy or weather and climate)* - *What natural events rely on time? (e.g., migration, seasons)* - *If seasons were shorter or longer, how would that affect natural events that depend on time?* ENGAGE IN DISCUSSION Students will discuss with their group/class whether each photo is	LEAD DISCUSSION Lead a discussion with the whole class about changing seasons. LEAD DISCUSSION What are **abiotic** and **biotic variables**? Go through the example

	biotic or abiotic. Then they will share out and record a definition. ENGAGE IN DISCUSSION Students will discuss: *What kind of timing do pollinators and plants rely on?* *How do bumble bees and plants coordinate their timing with each other?* *If bumble bees emerge later or earlier than "they should" then how does that influence flowers?* *How will an earlier spring affect bumble bees and flowers?* *How could low frost tolerance in flowers affect pollination?* [**Advanced Extension Content**] ENGAGE IN DISCUSSION Students will discuss: *How are bumble bees and plants able to compensate for a misalignment of timing?*	photos and help students decide how to define these terms. EXPLAIN/DISCUSS Then introduce the concept of **phenology** within slides: - *The timing of biological events in nature (e.g. flowering phases, migratory patterns in birds and fish, insect emergence, hibernation).* - Pollination timing between bumble bees and flowers. Overview of general bumble bee and flower lifecycle and abiotic variables that can affect it (within slide deck). - **Frost tolerance** affects bumble bees and plants differently, possibly affecting pollination. [**Advanced Extension Content**] EXPLAIN/DISCUSS - Introduce phenological shifts. **Phenological mismatch** hypothesis: *Misalignment of an essential interaction between species. (e.g. when there is pollinator emergence and floral bloom time misalignment or within bird migration and floral bloom times).* - An earlier spring is causing shifts in phenology that result in the misalignment of essential species interactions (e.g. insect emergence and

	Do you think generalist bumble bee species are affected differently than specialist bumble bee species are to phenological mismatch? [**End Extension Content**] ACTIVITY Follow along with the teacher's instructions for the NPN Activity. Explore plant-insect phenology interactions. Use the website provided (USANPN: Where Did Spring Arrive Early This Year?). The USANPN map is interactive and allows you to view phenology data in different ways. Students can filter the data for plants and bees. Students will follow along in the NPN Activity and record answers to provided questions in their note catcher. ENGAGE IN DISCUSSION Students will discuss:	floral bloom times). Therefore, leading to a negative effect on bee and plant populations. - However, new evidence shows that this is probably not the case between bumble bees and flowers. - A possible reason for this could be because most bumble bees are generalist species and can overlap with flowering plant time regardless of the timing of their blooms. **Generalist Species**: *not picky about their pollen selection* **Specialist Species**: *only interested in certain pollen from specific plants* [**End Extension Content**] PROMPT ACTIVTY During work time, display the (USANPN: Where Did Spring Arrive Early This Year?), which is an interactive map. EXPLAIN/DISCUSS - Explain ecosystem and human livelihood

	How does this have the potential to affect the social ecological system (SES) Impacts to: - *Social: relating to people (e.g., technology, economy, social interactions, agriculture)* - *Ecological: relating to ecosystems (e.g., structure and functions, birds, bees).*	implications [use slide deck as supporting resource]. Remind students that not all bees pollinate plants that humans use. You may consider introducing the vocabulary term **social-ecological systems**. It might be helpful to ask students what social and ecological mean separately, and then help students blend these ideas together to create one system (see definition of SES at the end of this document)
Class Period 3: Scientific Process and Creating Hypotheses (Explain)	RECALL Students will recall what they learned from exploring the NPN Map the previous day. - *What does this figure tell us about phenology?* - *If flowers are blooming earlier, how does this affect bumble bees?* ACCESS DATASET Open up the phenology dataset (Phenology Data - Students) and discuss with their group what the variables in each of the columns could mean. DEFINE VARIABLES Then they will go back to the Participatory Science Website and record the abiotic variable definitions in their note catcher from the glossary tab. (Or they can discuss what they mean as a class) • First flowering day	PROMPT RECALL Display a snippet of the NPN Map and ask students to recall what they observed in the map. INTRODUCE DATASET Introduce the Phenology dataset to students with the slides and **highlight that this is a participatory science dataset.** Ask students: *What makes this a participatory science dataset?* DEFINE VARIABLES Put the variables on the board and be sure to emphasize the limitation to the Bombus data: (Explain that limitations are a part of science and that many research projects will find there to be limitations to their data. Since there

	• Last flowering day • Peak flower count • Peak flowering duration • Flowering duration • Bombus occurrence *	are no absence data, this will be a limitation to theirs. This is a limitation because without absence data, we cannot properly analyze the *Bombus* frequency over time. Although, presence data CAN in this context tell us that certain species of *Bombus* are active in this area of CO).
	ENGAGE IN DISCUSSION Engage in discussion with classmates about data collection, and analysis. Example discussion question: *How do we define the scientific process?* As a class discussion, define "hypothesis." - *What is a hypothesis?* - *How is it different from a prediction?*	LEAD DISCUSSION Lead a discussion about data collection and the scientific process, data collection and analysis. See: https://undsci.berkeley.edu/ for more info on science as a dynamic and nonlinear process. Help the class come up with collective definitions of the scientific process, a hypothesis, and a prediction.
	ENGAGE IN ACTIVITY Student groups of 3-4 will choose 3 variables in the dataset. *What research questions about phenology could you answer using these variables?* Students can record 2 ideas in their note catcher. [Optional Extension: Work in small groups to categorize the variables in qualitative and quantitative groups].	LEAD ACTIVITY Arrange students in groups of 3-4. On a whiteboard (or app like Padlet), write the following question: *How could these variables help you answer questions about phenology?* Can provide students with example research questions: - How do you think the timing of phenological events of flowers in the dataset will occur over time? Earlier/later? - How do you think the timing of phenological events in

	CREATE HYPOTHESIS 1) Work in small groups of 3-4 to create a group hypothesis. Each student will record their hypothesis. 2) Can use the guiding questions provided by the teacher and in your note catcher to create a hypothesis. *How do you predict the timing of phenological events to occur over time within the following variables?* With which variables? Abiotic variables: temperature, precipitation (snowpack melt) Biotic variables: phenophases (e.g. bloom time, bloom duration, occurrence). With which species?	bumblebees in the dataset will occur over time? Earlier/later? - How do you predict plants to be affected over time by temperature and/or precipitation? - How do you predict bumble bees to be affected over time by temperature and/or precipitation? - How do you predict the climate variables to affect the interaction between plants and bumble bees? - How do you think bumblebee populations will be affected over time? DISCUSS HYPOTHESIS Discuss as a class, how to create a hypothesis. Remind students that a hypothesis is a tentative explanation. It can be written in first person or third person. ("I hypothesize that..." or "The explanation for ... is...") Challenge students to think critically about creating a *hypothesis* to explain phenological patterns. Encourage them to explore various natural and environmental factors that could be at play. Optional ideas to guide students: 1) Provide students with an example hypothesis. 2) Create one hypothesis as a class. 3) Encourage students to attempt to answer their research questions.

	Bees • Bumblebee (*Bombus*) Flowering plants • Nuttall's Larkspur (*Delphinium nuttallianum)* • Aspen Fleabane (*Erigeron speciosus)* • Little Sunflower *(Helianthella quinquenervis)* • Baker's Lupine (*Lupinus bakeri)* 3) Students will record which variables in the dataset they will need to test their hypotheses. REVIEW ASSIGNMENT Review the assessment rubric/description of assignment. Students can plan with their group to divide work. FOLLOW DEMO Students will revisit their hypothesis and navigate through How to Create a Figure as a class. Or they can do it on their own if they know how to do it. The entire	INTRODUCE ASSIGNMENT Introduce the Poster Assignment to the class and create a deadline for when students should have the poster completed. Students can also create a draft in their note catcher document as a final project instead. If appropriate, encourage students to work on this outside of class. If it is an e-poster, students can work asynchronously. Display example posters in slide deck and acknowledge that these posters have a lot of detail, and that theirs probably won't have as much due to the scope of this study. Instruct students that their poster should just follow the same general format. Guidance for creating a draft is in their note catcher document. LEAD DEMO Teacher will go through an Excel demo with the class to make a simple figure (creating a scatterplot chart). Also, invite students to show others if they know how to use Excel.

	class will create the same figure for this first part.	
Class Period 4: Constructing a Scientific Argument (Elaborate)	CREATE FIGURES Students will revisit their hypothesis and variables needed to create figures. Then, students will create 2-4 figures for their phenology studies. They can refer back to the 'How to Create a Figure in Microsoft Excel' document for a reminder on how to make a figure. INTERPRET GRAPHS Draw conclusions and organize findings into a poster • *Look for patterns in the graphs, what are you noticing over time?* • *Compare similarities and differences between the graphs. Do they relate to each other?* • *What inferences can you make about how this information applies to the SES?* CREATE/DRAFT POSTER Students will design posters presenting their hypothesis as a group with figures and a drawn conclusion. [review a model of a poster that the teacher provides].	PROMPT FIGURE CREATION Instruct students to refer back to their hypothesis and variables needed to make 2-4 figures. (Key in Phenology Data - Faculty). GRAPH INTERPRETAION GUIDE Guide students through how to interpret a figure. 1) Look at the X and Y axis. What do these variables mean? 2) Look for a pattern in the figure. a. Is there a trend in the data? b. An increase/decrease? c. Randomness? i. Randomness= information 3) Draw a conclusion about the data. DISPLAY EXAMPLE POSTERS Remind students of their poster presentation deadline and redisplay posters within slide deck. Instructions for creating a draft is in their HSNotecatcher Pollinator Phenology document.
Class Period 5: Presentation of Scientific Argument and	PRESENT/PEER REVIEW Students will present while other students listen and engage in peer review.	PROMPT PRESENTATIONS Hand out a peer evaluation form for students to fill out: Peer Evaluation Form. Ask each group to present their investigations to the class, and

Peer Evaluation (Evaluate)	ASK QUESTIONS Students will ask questions at the end of each presentation. CONCLUDE STUDENT PRESENTATIONS [Optional Extension] Students will submit a 1 paragraph self-reflection of: 1. Where they glowed 2. Where they want to grow **SUBMIT POST SURVEY** **Students will submit their Post-Survey**	the teacher will listen to student presentations. FOLLOW-UP QUESTIONS After each presentation, ask a few questions to engage in a class discussion about the broader implications of phenological shifts in natural/social systems. • encourage other students to ask questions as well COLLECT PEER EVALUATIONS An example assessment rubric is provided at the end of the assignment doc (Poster Assignment). Feel free to use it as a reference if you would like. [Optional Extension] Instruct students to reflect in their notebooks/electronic device where they would like to glow and grow. **PROVIDE LINK OR QR CODE** **Instruct students to take the post-survey from the QR code in the slides or from a link.** ****Teachers take module survey: AFTER: Teacher Module Survey**

Terms

Participatory Science: *Participatory Science is a ground-up approach to community science which can include volunteers, students, research scientists, and various community members. These groups work together to co-produce scientific knowledge.*

Phenology: *The timing of biological events in nature (e.g. flowering phases, migratory patterns in birds and fish, insect emergence, hibernation). Scientists often study how phenological events are affected by living and non-living variables, and how this affects alignment and misalignment of interactions among/between species.*

Abiotic Variable: *Non-living variables (e.g. climate data, precipitation, temperature).*

Biotic Variables: *Living variables (e.g. phenophase, bumblebee occurrence, flowering time)*

Phenophase: *A stage of an organism's lifecycle. (e.g. floral bloom time, first leaf, emergence of insect time, mating time).*

Frost Tolerance: *How much frost an organism to withstand without damage.*

Social-ecological system (SES): *Acknowledging that humans and nature are interconnected and do not function independently of one another. An overarching concept that recognizes the coupled interaction between social systems and ecological systems.*

Hypothesis: *An answer to a research question that is a tentative claim backed by the current supported evidence and knowledge available.*

Prediction: *A guess about what you think will happen not necessarily backed by evidence and knowledge.*

Phenology Dataset Variables:

- First flowering day: *day of the year when the first flowers on the plants opened*
- Last flowering day: *day of the year when the last flowers on the plants were visible*
- Peak flower count: *the highest number of flowers observed at once in the plot*
- Peak flowering day: *day of the year when the highest number of flowers were observed at once in the plot*
- Flowering duration: *the total of number of days the plants in that plot had flowers, from the first day to the last day*
- Bombus Occurrence: *presence of Bombus over time. Absence → NOT INCLUDED.*

(Explain that limitations are a part of science and that many research projects will find there to be limitations to their data. Since there is no absence data, this will be a limitation to theirs. This is a limitation because without absence data, we cannot properly analyze the Bombus frequency over time. Although, presence data CAN in this context tell us that certain species of Bom

Extension Vocabulary Terms:

Phenological mismatch: *Asynchrony of an essential interaction between species. (e.g. when there is pollinator emergence and floral bloom time misalignment or within bird migration and floral bloom times).*

Generalist and Specialist Species: *Generalist species are more adaptable to their environment and can rely on many resources, habitats, environmental conditions, and/or mechanisms for their survival. Specialist species are "special" in that they can only rely on very specific resources, habitats, environmental conditions, and/or mechanisms or resources for their survival.*

Phenology Dataset Sources:

iNaturalist. (2024). *Bombus observations in Rocky Mountain Biological Laboratory sites (1988–2023)* [Data set]. Retrieved from https://www.inaturalist.org/

McNutt, D.W., Underwood, N., and Inouye, B.D. (2023). Investigating effects of climate change on the phenology of subalpine wildflowers using a 45-year dataset. *Teaching Issues and Experiments in Ecology*, 19(14). https://tiee.esa.org/vol/v19/issues/data_sets/mcnutt/abstract.html

MICROSOFT EXCEL FIGURE GUIDE

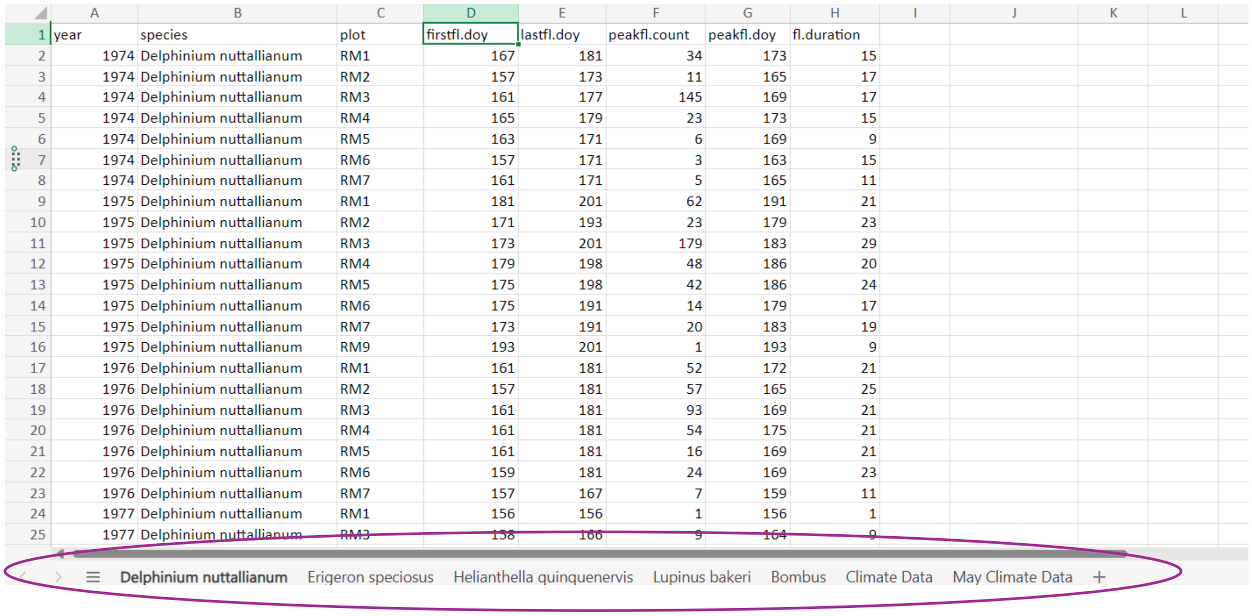
How to Create a Figure in Microsoft Excel

This guide walks you through how to create a scatter plot figure in Excel. This exercise can be fully adapted to Google Sheets if using that program. Hints are inserted throughout to address minor differences.

Demo:

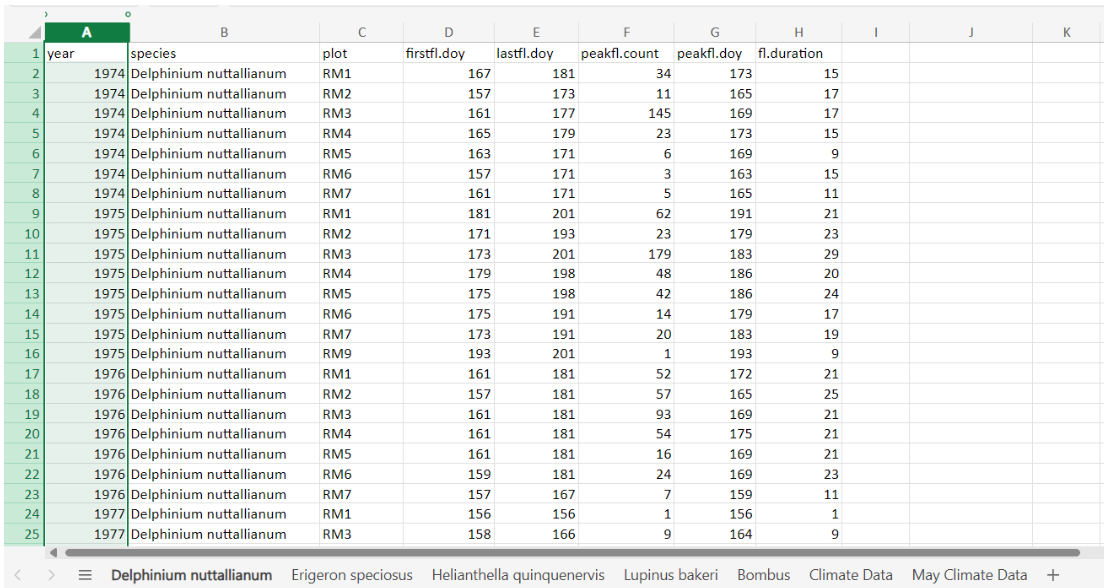
1. Open spreadsheet titled: "Phenology Student Data.xlsx"
2. Choose which plant or bumble bee data you would like to display by choosing one of the tabs at the bottom of the screen:

    a. *Delphinium nuttallianum*
    b. *Erigeron speciosus* (Aspen Fleabane)
    c. *Helianthella quinquenervis* (Little Sunflower)
    d. *Lupinus bakeri* (Baker's Lupine)
    e. *Bombus* (Bumblebee)



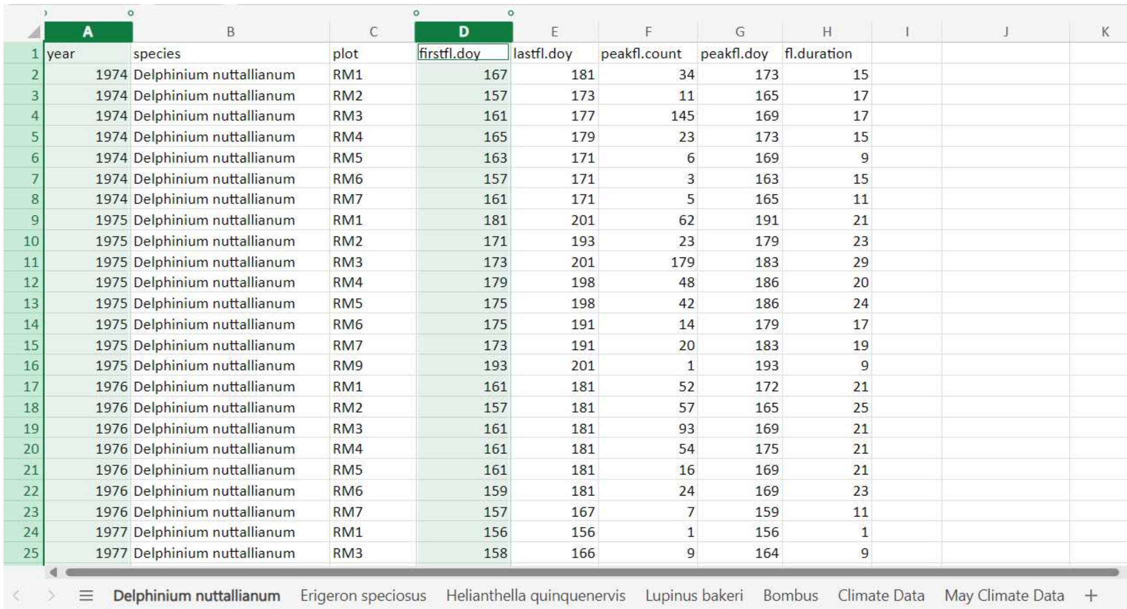
	A	B	C	D	E	F	G	H
1	year	species	plot	firstfl.doy	lastfl.doy	peakfl.count	peakfl.doy	fl.duration
2	1974	Delphinium nuttallianum	RM1	167	181	34	173	15
3	1974	Delphinium nuttallianum	RM2	157	173	11	165	17
4	1974	Delphinium nuttallianum	RM3	161	177	145	169	17
5	1974	Delphinium nuttallianum	RM4	165	179	23	173	15
6	1974	Delphinium nuttallianum	RM5	163	171	6	169	9
7	1974	Delphinium nuttallianum	RM6	157	171	3	163	15
8	1974	Delphinium nuttallianum	RM7	161	171	5	165	11
9	1975	Delphinium nuttallianum	RM1	181	201	62	191	21
10	1975	Delphinium nuttallianum	RM2	171	193	23	179	23
11	1975	Delphinium nuttallianum	RM3	173	201	179	183	29
12	1975	Delphinium nuttallianum	RM4	179	198	48	186	20
13	1975	Delphinium nuttallianum	RM5	175	198	42	186	24
14	1975	Delphinium nuttallianum	RM6	175	191	14	179	17
15	1975	Delphinium nuttallianum	RM7	173	191	20	183	19
16	1975	Delphinium nuttallianum	RM9	193	201	1	193	9
17	1976	Delphinium nuttallianum	RM1	161	181	52	172	21
18	1976	Delphinium nuttallianum	RM2	157	181	57	165	25
19	1976	Delphinium nuttallianum	RM3	161	181	93	169	21
20	1976	Delphinium nuttallianum	RM4	161	181	54	175	21
21	1976	Delphinium nuttallianum	RM5	161	181	16	169	21
22	1976	Delphinium nuttallianum	RM6	159	181	24	169	23
23	1976	Delphinium nuttallianum	RM7	157	167	7	159	11
24	1977	Delphinium nuttallianum	RM1	156	156	1	156	1
25	1977	Delphinium nuttallianum	RM3	158	166	9	164	9

3. Once you have selected a species to examine, select the column titled "Year" by clicking on the "A" above the column.



	A	B	C	D	E	F	G	H
1	year	species	plot	firstfl.doy	lastfl.doy	peakfl.count	peakfl.doy	fl.duration
2	1974	Delphinium nuttallianum	RM1	167	181	34	173	15
3	1974	Delphinium nuttallianum	RM2	157	173	11	165	17
4	1974	Delphinium nuttallianum	RM3	161	177	145	169	17
5	1974	Delphinium nuttallianum	RM4	165	179	23	173	15
6	1974	Delphinium nuttallianum	RM5	163	171	6	169	9
7	1974	Delphinium nuttallianum	RM6	157	171	3	163	15
8	1974	Delphinium nuttallianum	RM7	161	171	5	165	11
9	1975	Delphinium nuttallianum	RM1	181	201	62	191	21
10	1975	Delphinium nuttallianum	RM2	171	193	23	179	23
11	1975	Delphinium nuttallianum	RM3	173	201	179	183	29
12	1975	Delphinium nuttallianum	RM4	179	198	48	186	20
13	1975	Delphinium nuttallianum	RM5	175	198	42	186	24
14	1975	Delphinium nuttallianum	RM6	175	191	14	179	17
15	1975	Delphinium nuttallianum	RM7	173	191	20	183	19
16	1975	Delphinium nuttallianum	RM9	193	201	1	193	9
17	1976	Delphinium nuttallianum	RM1	161	181	52	172	21
18	1976	Delphinium nuttallianum	RM2	157	181	57	165	25
19	1976	Delphinium nuttallianum	RM3	161	181	93	169	21
20	1976	Delphinium nuttallianum	RM4	161	181	54	175	21
21	1976	Delphinium nuttallianum	RM5	161	181	16	169	21
22	1976	Delphinium nuttallianum	RM6	159	181	24	169	23
23	1976	Delphinium nuttallianum	RM7	157	167	7	159	11
24	1977	Delphinium nuttallianum	RM1	156	156	1	156	1
25	1977	Delphinium nuttallianum	RM3	158	166	9	164	9

4. Hold down the "ctrl" key and select the column titled "firstfl.doy" (plants) or "occurr.doy" (bumblebees) by clicking the capitalized letter above the column.



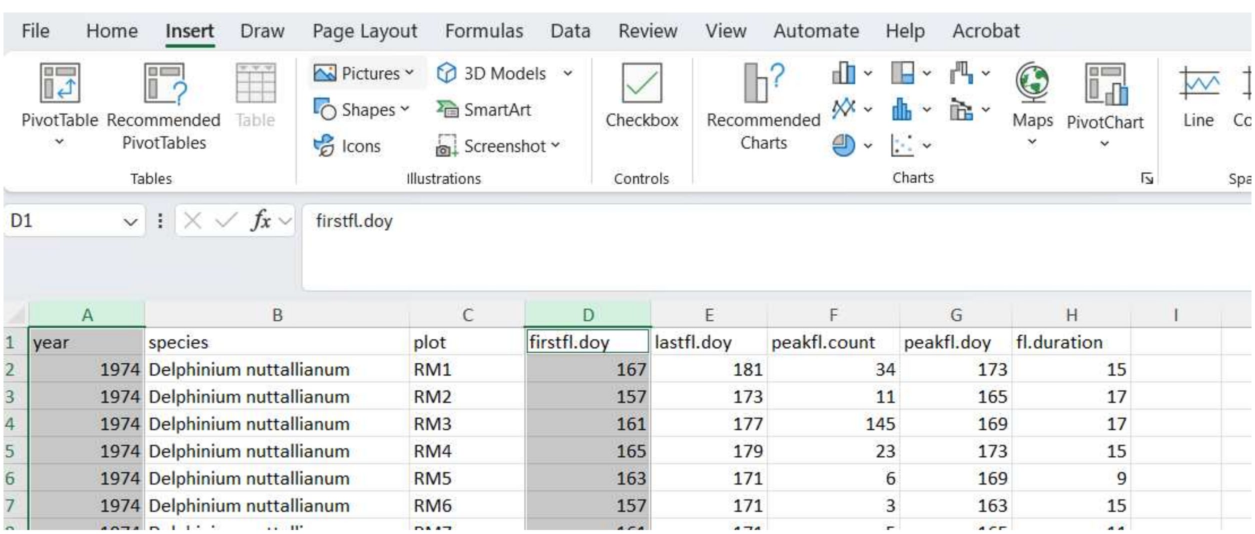
	year	species	plot	firstfl.doy	lastfl.doy	peakfl.count	peakfl.doy	fl.duration
2	1974	Delphinium nuttallianum	RM1	167	181	34	173	15
3	1974	Delphinium nuttallianum	RM2	157	173	11	165	17
4	1974	Delphinium nuttallianum	RM3	161	177	145	169	17
5	1974	Delphinium nuttallianum	RM4	165	179	23	173	15
6	1974	Delphinium nuttallianum	RM5	163	171	6	169	9
7	1974	Delphinium nuttallianum	RM6	157	171	3	163	15
8	1974	Delphinium nuttallianum	RM7	161	171	5	165	11
9	1975	Delphinium nuttallianum	RM1	181	201	62	191	21
10	1975	Delphinium nuttallianum	RM2	171	193	23	179	23
11	1975	Delphinium nuttallianum	RM3	173	201	179	183	29
12	1975	Delphinium nuttallianum	RM4	179	198	48	186	20
13	1975	Delphinium nuttallianum	RM5	175	198	42	186	24
14	1975	Delphinium nuttallianum	RM6	175	191	14	179	17
15	1975	Delphinium nuttallianum	RM7	173	191	20	183	19
16	1975	Delphinium nuttallianum	RM9	193	201	1	193	9
17	1976	Delphinium nuttallianum	RM1	161	181	52	172	21
18	1976	Delphinium nuttallianum	RM2	157	181	57	165	25
19	1976	Delphinium nuttallianum	RM3	161	181	93	169	21
20	1976	Delphinium nuttallianum	RM4	161	181	54	175	21
21	1976	Delphinium nuttallianum	RM5	161	181	16	169	21
22	1976	Delphinium nuttallianum	RM6	159	181	24	169	23
23	1976	Delphinium nuttallianum	RM7	157	167	7	159	11
24	1977	Delphinium nuttallianum	RM1	156	156	1	156	1
25	1977	Delphinium nuttallianum	RM3	158	166	9	164	9

a. What does "day of year" mean?

b. Day of year means the day between 1 and 365 that each date falls on (e.g. 1= January 1st, 2= January 2nd).

c. The year of collection is in a separate column

5. Click the 'Insert' tab. Here, you will find all kinds of chart options. Observe the different graph types and note how that helps you to visualize the data. Then, if you haven't already, set the data visualization to the scatter plot (use the first listed type, just called "scatter"). (Hint: if using Google Sheets click insert>chart)



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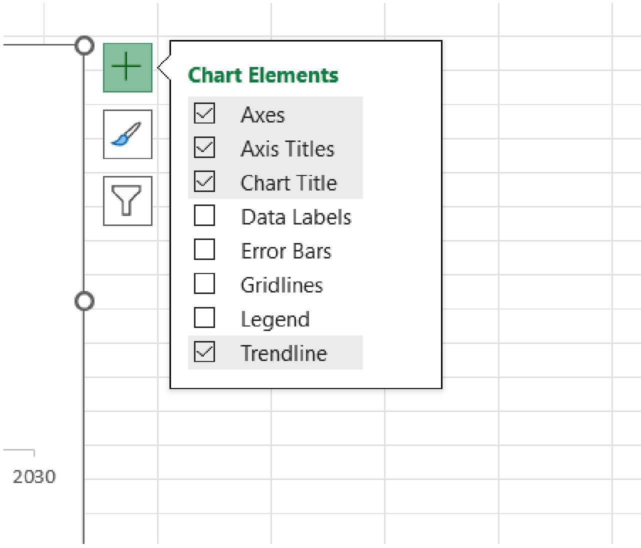
4	1974	Delphinium nuttallianum	RM3	161	177	145	169	17
5	1974	Delphinium nuttallianum	RM4	165	179	23	173	15
6	1974	Delphinium nuttallianum	RM5	163	171	6	169	9
7	1974	Delphinium nuttallianum	RM6	157	171	3	163	15

6. Add additional chart elements by clicking the "+" button in the top, right corner. (Hint: if using Google Sheets double click on graph)



   a. Check the 'Axis Titles' box to add and edit axis titles.
   b. Label the x-axis as "Year"
   c. Label the y-axis as "Day of Year"
   d. Edit the title by clicking on it in your graph. Label it "First Flowering Days of [species chosen] 1974-2020" or if using *Bombus*, "*Bombus* Occurrence 1988-2024"
   e. Check the 'Trend Line' box to add a trend line. (Hint: if using Google Sheets double click on graph, Chart Editor>Customize>Series>scroll to the bottom and select 'Trendline')
      i. What do you think a trend line shows? Discuss it with your group.
      ii. [Optional Extension] Is this trend positive, negative, or neither? What does that mean for this data?

PEER EVALUATION FORM

Name: ___________________________

Peer Evaluation Form—Poster Presentation

Group Number or Name ______________________________

1. Identify two aspects of the poster that were strengths:

   1a. Why were these helpful for you as a poster reader:

2. Identify two aspects of this poster that can be improved:

   2a. How might these changes be helpful for you as a poster reader?

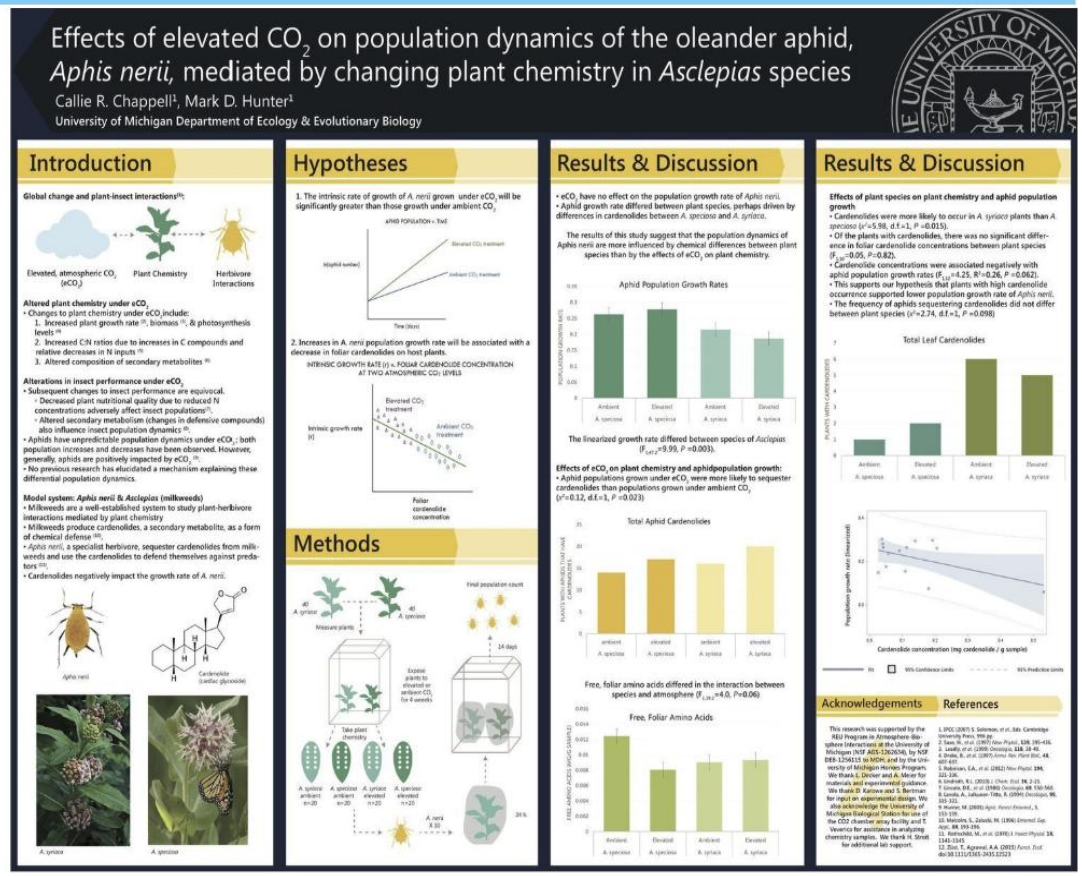
3. What might you change about your own poster now that you have read and evaluated this one?

POSTER EXAMPLE FROM SLIDES

Organize your Findings into a Poster

Draft your poster into your note catcher.

- Title
- Introduction
- Hypothesis
- Methods/Approach
- Results
- Discussion/Conclusion
- References



CLIMATE CHANGE ATTITUDES AND ENVIRONMENTAL MOTIVATION SURVEY
(Christensen & Knezek, 2015; Aghekyan, 2019)

Climate Change Attitudes Survey (CCAS)

1. I believe our climate is changing.
2. I am concerned about global climate change.
3. I believe there is evidence of global climate change.
4. Global climate change will impact our environment in the next 10 years.
5. Global climate change will impact future generations.
6. The actions of individuals can make a positive difference in global climate change
7. Human activities cause global climate change.
8. Climate change has a negative effect on our lives.
9. We cannot do anything to stop global climate change.
10. I can do my part to make the world a better place for future generations.
11. Knowing about environmental problems and issues is important to me.
12. I think most of the concerns about environmental problems have been exaggerated.
13. Things I do have no effect on the quality of the environment.
14. It is a waste of time to work to solve environmental problems.
15. There is not much I can do that will help solve environmental problems
16. [for teacher participants] Please explain how you integrate climate change into your curriculum (open response).
17. [for teacher participants] Please explain your interest in participating in this project (open response) (e.g., to expand your climate change teaching resources, to learn how to teach climate change).

Science Identities, Expectations of Success in Science, Values of Science, and Environmental Attitudes Survey (SIEVIA)

1. Learning about environmental science in school will help me to succeed later in life.
2. I am confident I can master the skills taught in my science class.
3. I consider environmental science topics very interesting and engaging.
4. When it comes to learning environmental science, I think of myself as a science person.

5. My peers and teachers think that I am knowledgeable in environmental science.
6. I am certain I can figure out how to do the most difficult science classwork.
7. I can use technology for learning environmental science content.
8. My friends and family recognize me as a future environmental scientist.
9. It is important to me that I look smart in my science class.
10. I would like to become more active on important environmental issues.
11. One of my goals is to show others that I am good at environmental science.
12. It is important for all people to be engaged in important environmental issues
13. I want to be engaged in important environmental issues as a participatory scientist.
14. I am interested in volunteering in my community to help solve environmental issues.

Demographic Information

1. What is your student ID number?
2. What is your grade level?
   - 6th
   - 7th
   - 8th
   - 9th
   - 10th
   - 11th
   - 12th
3. What school do you go to?
   - [name] Middle School
   - [name] Middle School
   - [name] Middle School
   - [name] Middle School
   - [name] High School
   - [name] High School

- [name] Expeditionary Learning School
- Other

4. What's your teacher's name?
5. How old are you?
   - 11
   - 12
   - 13
   - 14
   - 15
   - 16
   - 17
   - 18
6. Which of the following best applies to you? Please select as many as you identify with.
   - American Indian or Alaska Native
   - Asian
   - Black or African American
   - Hispanic or Latino
   - Native Hawaiian or Other Pacific Islander
   - White
7. How do you identify your gender?
   - Male
   - Female
   - Non-binary
   - Another gender identity
   - Unsure

PLACE-BASED EDUCATION AND COMMUNITY CONTEXT INTERVIEW GUIDE

(Conlon, Balgopal, et al., 2025)

1. Can you please introduce yourself, by providing your background, experience and knowledge around environmental science/biology, and describe your position/role at your school?

    a. How would you say your background has led you to where you are now?

2. How would you describe your interactions with nature/environment during your childhood?

    a. How did your family/friends/community engage with nature, if at all?

3. How would you currently describe your relationship to the environment?

    b. What do you think people gain, if anything, by interacting with the environment?

4. What are your perceptions of the environment that are also relevant to your local community?

5. How would you describe yourself as a teacher (teaching styles, strengths, etc.)?

6. Explain your understanding of place-based education and the role it may play in teaching

7. Can you help me understand how your ideas about PBE developed? (e.g. from your personal experiences, hobbies, or education)?

8. Do you currently integrate PBE into your curricula, and if so, can you describe these?

9. How do you integrate discussion of socio-scientific issues into your curriculum?

10. How do you choose to frame these socio-scientific issues to your students?

11. How do you integrate discussion of climate change into your curriculum?

12. How do you choose to frame topics of climate change to your students?

13. By your own evaluation, to what extent, if any, would you say your own experiences and perceptions about the environment and climate change influence how you teach about these topics?

14. What's your motivation to use place-based education?

15. What is your motivation to teach about a changing environment?

16. How long have you been teaching climate change in your class

    a. Do you think it has changed over time?

    b. Do you integrate the state standards?

17. How does place-based education fit into your teaching?

18. Can you describe the motivation of your students to be environmentally engaged?

19. How do your environmental values align or misalign with the community?

20. [Contextualize results to teacher] Students at the rural school had lower motivation to begin in comparison to suburban students, what do you think might explain the difference in comparison?

DESCRIPTIVE STATISTICS

Descriptive statistics of significant SEVT or CCAS constructs. Mean pre and post results within each suburban and rural population.

SEVT construct	Locale	Time	Mean	df	SE
Environmental Science Identity	Suburban	Pre	2.60	55	0.0958
	(n=56)	Post	2.93	55	0.120
	Rural	Pre	2.45	41	0.128
	(n=42)	Post	2.39	41	0.157
Environmental Science Values	Suburban	Pre	3.19	55	0.0966
	(n=56)	Post	3.28	55	0.0940
	Rural	Pre	3.03	41	0.139
	(n=42)	Post	2.76	41	0.152
Environmental Science Motivation	Suburban	Pre	3.42	55	0.0928
	(n=56)	Post	3.52	55	0.104
	Rural	Pre	2.91	41	0.147
	(n=42)	Post	2.74	41	0.163
Don’t believe, no need to try	Suburban	Pre	2.52	55	0.112
	(n=56)	Post	2.44	55	0.129
	Rural	Pre	2.60	41	0.147
	(n=42)	Post	2.83	41	0.138
‘I can’t change anything’	Suburban	Pre	2.27	55	0.110

(n=56)	Post	2.28	55	0.132
Rural	Pre	2.17	41	0.126
(n=42)	Post	2.48	41	0.109

SEVT CODEBOOK

SEVT codebook used for teacher interviews. Each code is defined with a provided example. A dash indicates no further subcodes to the main code.

Code	Definition	Subcode 1	Definition	Subcode 2	Definition	Example
Environmental Science Identity	Any reflection of the teacher's character when it comes to the environment or a description of the type of environmental person they are, but not why it's important to them. Must be specifically referring to themselves.	–	–	–	–	*"So kind of watching the impacts of it has been unique. I guess, way to say it that probably ties into why I went into science in the first place, kind of where, where I developed, I guess, as a person…I do [feel obligated to protect the environment]. I mean, that's my identity."*
Environmental Science Values	Any level of importance, usefulness, enjoyment, or lack thereof when referring to the environment or environmental science.	Attainment	The teacher values the environment or environmental science because of the personal relevance it has to them currently or in the future. Alternatively the teacher values it for their students lives to shape them into who they envision. Alternatively, there is a sense a passion	Self-focused	The importance of environmenta l science centers around the teacher's life outside of school which may or may not connect to them in the classroom.	*"How I wish they saw it [the environment] what would be more as a gift and also as something that is you are just as much a part of it. Of the environment as they are and to to as more of a neighbor I guess and and*

			about the topic or reads as a core principle to the teacher.			*something to share."*
				Student-focused	The teacher views environmental science topics as important for their students. The teacher wants an outcome for the students within this field and teaches in a certain way to get them there. Alternatively, there is a sense a passion about the topic or reads as a core principle to the teacher.	*"So then, even if they don't go into a scientific field to try to fix it, they can at least vote and think when they choose a new politician, or choose a new pathway, that they're not just going in blind, that they're like, wait, you're saying, what about this? And are able to make an informed decision, rather than, you know, a feeling."*
		Utility	The teacher values the environment because it is useful to them or requires little effort to integrate into their life. Or as a teacher it makes sense to integrate the topic into the class.	Self-focused	This teacher values the environment for its usefulness to their personal life or because being a steward requires little effort to fit it into their life. Or, as a teacher, they are required to teach the subject or it applies to their class.	*"But I think it was also a lot of how to take care of the land because the better you took care of the land, the better the hunting was."*
				Student-focused	The teacher values environmental science because it	*"You can take a lot of our location based stuff, and the kids can dive*

					applies to their students' lives and makes sense for their students to learn the topic.	*in. They have that connection. They've lived it. And so we could take that and use it as a launching point. You can get the kids to go higher than if a kid has never experienced any of the nature and they're learning about in a textbook."*
		Cost	The teacher does not value being an environmental steward because this takes away from my life in another way.	–	–	*"And so it's not a distance thing. It's a safety thing because I have to bike on Highway One. And I don't feel comfortable biking in the dark."*
		Intrinsic	The teacher enjoys doing something or is appreciative of something related to the environment or to teaching environmental science.	–	–	*"I grew up with a deep appreciation for that [the outdoors] as fishermen as a kid."*
Expectations of Success in Environmental Science	Any experiences, knowledge, or expectations about the future of the environment, or teaching environmental science. Any confidence in their	Knowledge	Any specific environmental science knowledge (social-ecological or ecological) that highlights environmental causes, impacts or solutions. Excluded when used to describe a teaching style.	Local Knowledge	Any social-ecological or ecological knowledge that applies to their immediate context and/or lived experiences in the community.	*"Yeah, well, normally, we don't have all these beetles, but the to kill off beetle larva...normally we have cold winters up here, and it has to be the trees that the beetle's eggs*

	environmental knowledge.					*are in, if it's below freezing for a month straight or longer, It kills off 90% of the beetles... [warmer winters]... it's not going to interrupt the larval stage, and so all those eggs are going to be able to survive it. And so we're going to have an increase in this [beetle killed trees].”*
				General Knowledge	Any social-ecological or ecological general understanding of a broader context. This includes broader knowledge relative to the state they live or world.	*“My perception of wildlife is that we're going through a great extinction event right now and that we are losing more and varieties of animals. than possibly in human history.”*
		Expectancies	Any stated confidence in their environmental science abilities (in teaching, in their content knowledge) or lack of confidence/expectations in the future of climate change. Any expectations about how environmental	Powerlessness in environmental challenges	Any expression of doubt that environmental challenges can be addressed in the future, including feelings of powerlessness, a belief that they	*“that when people went and tried to enjoy this, this gift of like, open public lands. They didn't bother to learn how to take care of it. And so trash everywhere when the*

			science is taught or how students perceive material.		personally have no role or a limited role in the issue, or do not believe in others in solving environmental issues.	*national parks closed down, they talked about toilets being destroyed and things like that, that if they're doing that in the parking lot, you know, there that means they're doing the same thing everywhere else."*
				Expectations as an environmental science teacher	Anything the teacher expects to happen in their group of students as a result of teaching an environmental science topic. This does not include mitigative teaching strategies to these expectations.	*"And there's always gonna be situations where kids or parents get mad, but I've had very few problems with that, probably count on one hand where I've had actual issues that escalated beyond a discussion with the student."*
				Confidence in environmental knowledge	Any expression of the teacher sharing how they feel confident in their environmental science knowledge.	*"I've gotten pretty good with the environment, environmental aspects up in our county."*
		Experiences	Any individual environmental or environmental science-related	Job/education	Any environmental science experience	*"Our school did trips through a program called*

			experience either in the classroom, at a different job, or within their personal life.		relating to their job or previous education experiences.	*'co-pack' where we would take them, most of the trips went to Utah."*
				Outdoor recreation	Any recreation experience they have had outdoors such as camping, hiking, wildlife viewing, gardening etc. Excluded if it's within an educational setting.	"*I've gone hiking and backpacking have been unique all over the United States. So I've gotten to see a lot of different types of wildlife in their native habitat."*
				Environmental challenges	Any challenge relating to the environment such as a natural disaster, other climate change result, the teacher experienced.	*"And in 2019 we had no 2020 we had the East troublesome fire up in Granby, which was devastating, took the entire county burned down. We got evacuated"*
Environmental Science Motivation	Any environmental actions that are exhibited outside of teaching that mitigate climate change or actions as an environmental science teacher that provide additional environmental	Personal life	Actions that are environmentally conscious in the teacher's personal life outside of school. The purpose of the action should be specific to reducing the teacher's environmental footprint.	–	–	*"I put in a heat pump, because we have solar and that way my heating and cooling of my house, the majority of the time utilizes that. I switch to an electric car instead of a hybrid because I have solar so I can charge it when*

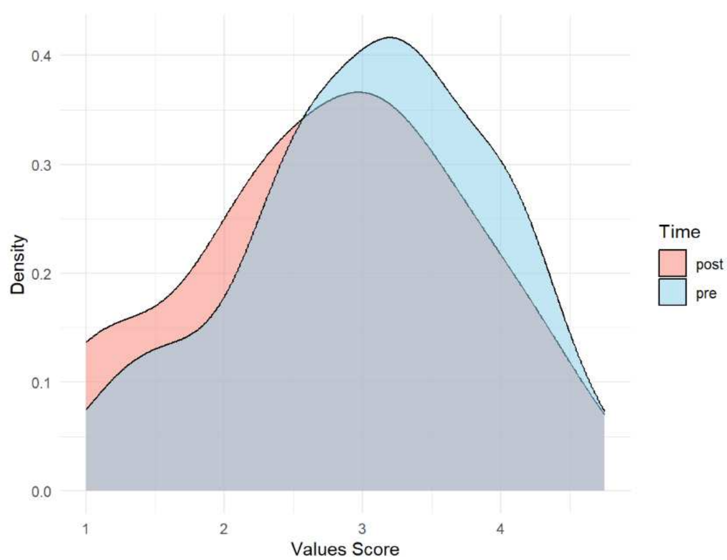
	science experiences.					*I, you know, in I don't know, in theory, straight from sun to car to driving without having to utilize any like fossil fuels or things like that. I bike when I can and do all of that.”*
		Professional life	Actions that are not necessarily taken to reduce an environmental footprint, but show the teacher goes above and beyond their day-to-day teaching to create environmental science experiences for students. This includes professional development.	–	–	“*But basically, it's a class that I designed specifically to get kids outside and learn skills and be introduced to basically outdoor activities that they may not otherwise be introduced to. Everything from outdoor survival, orienteering, archery, fly fishing, outdoor cooking, fire-making, shelter-building things like that, where it can be more of a lifelong interest for them, or at least give them the chance to try it out.”*

DISTRIBUTION OF PRE AND POST SURVEY RESPONSES

Suburban Environmental Science Identity

Suburban mean environmental science identity probability distribution of pre and post survey scores. In the pre survey there was a higher density of 'unsure' responses (Likert-scale 3) than there were in the post survey. More students were skewed-left in the pre survey and then moved to skewed-right in the post survey towards agreement.

Rural Environmental Science Values



Rural mean environmental science value probability distribution of pre and post survey scores. In the pre survey there were more students who answered as 'unsure' (Likert-Scale 3) than there were in the post survey. Students also started as more skewed right and then ended more skewed left into disagreement.

CLIMATE CHANGE ATTITUDES SURVEY RESULTS

Factorial Results

All constructs except 'don't believe, no need tro try' and 'I can't change anything' which are included in our main findings. Linear mixed-effects factorial results of the CCAS constructs. The locale is the suburban or rural school. The time is the time of survey, pre or post. ***$P < 0.001$ **$P < 0.01$ *$P < 0.05$.

SEVT construct	Fixed effects	Den DF	*F* value	*p* value
'Read to take action'	Locale	96	3.0891	0.08201
	Time	96	3.4154	0.06767
	Locale:Time	96	0.0936	0.76029
'Accept responsibility for the environment'	Locale	95.869	1.0288	0.3130
	Time	94.591	1.1907	0.2780
	Locale:Time	94.591	0.0000	0.9949

Pairwise Comparisons

All constructs are included except 'don't believe, no need tro try' and 'I can't change anything' which are included in our main findings. Pairwise comparisons of each CCAS construct within each locale (suburban or rural) and time (pre or posttest) contrasts from the LMM. ***$P < 0.001$ **$P < 0.01$ *$P < 0.05$.

SEVT construct	Contrast	Estimated mean difference	SE	df	t ratio	*p* value
'Ready to take action'	Rural (post-pre)	-0.175	0.123	96	-1.425	0.1575
	Suburban (post-pre)	-0.125	0.106	96	-1.178	0.2418
	Pre (rural-suburban)	-0.222	0.162	154	-1.369	0.1731
	Post (rural-suburban)	-0.271	0.162	154	-1.675	0.0960
'Accept responsibility for the environment'	Rural (post-pre)	-0.0786	0.1090	94.1	-0.722	0.4720
	Suburban (post-pre)	-0.0795	0.0957	95.1	-0.831	0.4080
	Pre (rural-suburban)	-0.158	0.171	136	-0.921	0.3585

Post (rural-suburban)	-0.157	0.171	136	-0.916	0.3613