UNIVERSITY OF OKLAHOMA GRADUATE COLLEGE

HOT TOPICS IN EARTH SCIENCE: DEVELOPMENT AND EVALUATION OF A CLIMATE CHANGE-CENTERED PROFESSIONAL DEVELOPMENT PROGRAM FOR SECONDARY SCIENCE TEACHERS

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HOT TOPICS IN EARTH SCIENCE: DEVELOPMENT AND EVALUATION OF A CLIMATE CHANGE-CENTERED PROFESSIONAL DEVELOPMENT PROGRAM FOR SECONDARY SCIENCE TEACHERS

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Abstract

There is a limited window to address global climate change (GCC) if we want to avoid the most severe impacts (Millar et al., 2017). This time window has almost closed, with little actual progress made toward significant changes in policy or consumption patterns. Simultaneously, misinformation and disinformation campaigns still influence the general understanding of GCC. The Next Generation Science Standards (NGSS) include the integration of climate change education into elementary and secondary science as a critical component (NGSS Lead States, 2013) but some states—such as Oklahoma—fail to meet the science standards set by NGSS (e.g. Colston & Ivey, 2015). Teachers might avoid these topics owing to several (perceived) barriers (Ennes et al., 2021; Li et al., 2021):

1. Time constraints
2. Lack of support (institutional, curricular, societal)
3. Complexity of the science

In order to improve the teaching of climate change science, any professional development (PD) program that addresses climate change at the forefront of its topics should also seek to address these barriers by providing implementable resources and strategies.

Hot Topics in Earth Science (HTES) was a PD developed for in-service secondary science teachers (Grades 6-12) in central Oklahoma. It had a dual focus on pedagogical and curricular approaches to teaching climate change science at the secondary level and the associated content. Techniques were discussed explicitly by facilitators and modeled by subject matter experts through content designed to challenge and broaden teachers' conceptual understandings related to climate change science. Teachers were encouraged, with the support of science education personnel, to develop high-context lesson sequences to facilitate with their students throughout the academic year. Here we present a summary of our approach to the PD, samples of teacher products and responses over the course of the PD, and a reflection on successes and areas of improvement for similar PDs in the future.

Ch 1. Setting the Scene

Background of the Study

Anthropogenic Global Climate Change (GCC) is a far reaching and interdisciplinary problem that will, ultimately, impact everyone on the planet. There is a limited window to address, mitigate, and adapt to these changes before we start to see some of the harsher impacts (Millar et al., 2017). That window has largely closed with little in the way of substantial change in key areas such as policy changes and consumption habits. The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report clearly describes the urgency of the problem and the necessity of implementing mitigation methods (Calvin et al., 2023). However, misinformation and disinformation campaigns have left scars in the public and successfully obfuscated many policymakers' understanding of GCC, its causes, and its effects (Lewandowsky, 2021; Oreskes & Conway, 2011; Treen et al., 2020).

Mis- and Disinformation in GCC Information Dissemination

There is a long-standing consensus (97%) in the scientific community regarding global climate change and the anthropogenic causes thereof (Calvin et al., 2023; Oreskes, 2004; Oreskes & Conway, 2011). Nevertheless, these data have failed to garner action on the part of the global and national populace (Howe et al., 2015; Marlon et al., 2022). Comprehensive climate change education must be prepared to not only react to, but to pre-emptively address mis- and disinformation about climate change and climate change science. As Lewandowsky (2021) summarized in their discussion of mis- and disinformation in the field of climate change:

1. Climate change challenges our cognitive abilities and the worldviews of many.
2. Because addressing climate change has serious economic and political implications, any communication takes place in an environment of adversity.

3. Providing information about climate change, in particular about the scientific consensus and explanations of why it occurs, can enhance people's acceptance of science.
4. Culturally aligned messages and messengers are more likely to be successful.
5. Through a process known as inoculation, climate misinformation can be rebutted or, ideally, defanged before it is encountered.

Through the utilization of *agnotology*, a term coined to describe the study of ignorance and how it can be socially and culturally constructed, mis- and disinformation can actually be used as a teaching tool for climate change-related topics (Bedford & Cook, 2013; Oreskes & Conway, 2011).

GCC and Education

The Next Generation Science Standards (NGSS) include the integration of climate change education into elementary and secondary science standards (NGSS Lead States, 2013). "ESS3D" is titled "Global Climate Change"; where "ESS" stands for Earth and Space Science discipline, "3" indicates that it is the third core idea in the ESS discipline, and "D" delineates it as the fourth sub-idea within the discipline. Additionally, each code is preceded by a grade band of "K-5" for kindergarten through 5th grade, "MS" for middle school, and "HS" for high school and followed by a number instead of a D to clarify a specific topic. These include standards that explicitly mention climate change (see Table 1) and those that are related to, but do not explicitly mention, broader GCC topics. This is not to say that other standards cannot be related to GCC.

Fostering scientifically literate, environmentally conscious individuals and community advocates is essential for facing the future of a growing climate emergency and the resulting consequences for much of humanity. The education system is the perfect context for conveying content and concepts to assist in the development of individuals and citizens capable of making informed decisions about the world around them. In this scenario, science teachers act as key agents of change in promoting awareness, understanding, and action on the topic of climate change. However, accomplishing this requires a firm grasp on the background scientific concepts, the nature of science, and methodologies necessary to effectively teach such a complicated topic. As such, it is important to create opportunities for professional development capable of equipping educators with the tools necessary to teach the science of climate change and its impacts.

The Reality of GCC Academic and Pedagogical Understanding in Oklahoma (OK)

In the state of Oklahoma, the majority (~60%) of the population accepts that climate change is happening but lags significantly behind national average of 72%. Additionally, less than 50% of Oklahomans attribute climate change to human activity (Howe et al., 2015; Marlon et al., 2022). Oklahoma's energy sector employment is three times the national average (The 2019 U.S. Energy & Employment Report, 2019) and is one of the major sites of misinformation and disinformation campaigns about anthropogenic CO_2 emissions, extending to the point of climate science denialism (Björnberg et al., 2017; Brulle, 2020; Bush, 2020; Colston & Ivey, 2015; Grasso, 2019).

Curricular resources highlighting climate science are limited for Oklahoma secondary teachers, and those that do exist do little to address disinformation about anthropogenic CO_2 emissions and climate denialism. One example includes teacher PD and curricular resources that use illustrated children's books, virtual field trips, video lessons, and a petroleum themed mascot all supported financially through the state's oil and gas industry represented by the Oklahoma Energy Resources Board (OERB). These resources celebrate fossil fuels, while omitting the consequences of their use. In 2019, 98% of Oklahoma school districts had OERB-trained teachers (OERB Annual Report: Building a Better Oklahoma, 2019). However, for teachers who do not have decent support structures or a strong science background, the OERB offers easily accessible lesson plans and materials, provides $100 stipends for attending one-day PDs, and distributes $2,000 grants to schools that host their workshops.

Table 1.

Next Generation Science Standards Explicitly Discussing Global Climate Change

Code	Standard	Clarification Statement and Assessment Boundary
MS-ESS3-5	Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.	**Examples** of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). **Examples** of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.
HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate	**Examples** of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition. **Assessment** of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution
HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have	**Examples** of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). **Examples** of the results

	influenced human activity.	of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.
HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.	**Examples** of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). **Examples** for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).
HS-ESS3-5	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	**Examples** of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition). **Assessment** is limited to one example of a climate change and its associated impacts.

Although the NGSS include climate change education in elementary and secondary science as a critical component (NGSS Lead States, 2013), some states—such as Oklahoma—have a history of failing to meet the science standards set by NGSS (e.g. Colston & Ivey, 2015). Oklahoma's current science standards (Oklahoma Academic Standards for Science, OAS-S) were officially adopted in 2020 and first evaluated by the state's department of education in the 2022-2023 school year. While much of the language is inspired by—if not directly copied from—the NGSS, they are often less explicit. The National Center for Science Education and the

Texas Freedom Network Education Fund rated Oklahoma's standards in 2020 on its climate change content, leaving the following comment in their report (MAKING THE GRADE? How State Public School Science Standards Address Climate Change, 2020):

> Oklahoma received a B-, with mostly mediocre scores across the board, although slightly better for addressing the severity of climate change and possible solutions. One reviewer: "Oklahoma's (draft) standards adopt the format, style (including color scheme), and very often the exact same wording as the NGSS. Subtle editorial changes — especially deletions — however, have the net effect of de-emphasizing NGSS's clarity regarding climate change." The state received decent scores on preparing students for future study and for responsible participation in civic deliberation on the issue (pg. 18).

"Climate change" is explicitly stated four times in the OAS-S (Table 2) and can be considered directly proximally associated with several additional standards. Examples of standards that could be considered proximally associated to climate change topics appear in the Earth Space Science standards in 7th grade science, as well as Environmental Science courses:

> ES.ESS3.2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios on large and small scale.*

> 7.ESS3.3 Apply scientific principles to design a method for monitoring and minimizing human impact on the environment.*

> 7.ESS3.4 Construct an argument supported by evidence for how increase in human population and per-capita consumption of natural resources impact Earth's systems.

Table 2.

OAS-S Language That Explicitly Mentions GCC

Code	Performance Expectation	Clarification Statement and Assessment Boundary
3.LS4.4	Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.	**Clarification Statement:** Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms. **Assessment Boundary:** Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.
7.ESS3.5	Obtain, evaluate, and communicate evidence of the factors that have caused changes in global temperatures over the past century.*	**Clarification Statement:** Examples of evidence can include tables, graphs, and maps of global and regional temperatures; atmospheric levels of gases such as carbon dioxide and methane; and the impact humans have on the environment. **Assessment Boundary:** N/A
B.LS4.4	Construct an explanation based on evidence for how natural selection leads to adaptation of populations.	**Clarification Statement:** Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or adaptation of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations. **Assessment Boundary:** N/A
EN.LS2.7	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.	**Clarification Statement:** Examples of human activities can include habitat destruction, pollution, introduction of invasive species, overexploitation, climate change, overpopulation, urbanization, and building dams. **Assessment Boundary:** N/A

*Note: the associated disciplinary core idea states that students are to understand “atmospheric changes and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge (such as understanding of human behavior) and on applying that knowledge wisely in decisions and activities.

The Problem from Teachers' Perspectives

Global Climate Change (GCC) is a complex and multifaceted topic, one that many teachers are not confident about teaching (Li et al., 2021). Whether this reticence stems from a limited knowledge or misconceptions, or due to a difficulty in tackling content with deep socio-political and emotional connections; when paired with a lack of funding and support, as well as related but ambiguous standards, GCC is easily relegated to a single class period or activity (*Introduction to the OKScience Framework*, n.d.; MAKING THE GRADE? How State Public School Science Standards Address Climate Change, 2020). That said, Ennes et al. (2021) found that the primary barrier perceived by teachers is time. In these cases, that time could be described in several ways, one being the time to create or adapt materials for their specific context, especially when it can be difficult for teachers to know where to look to find and differentiate evidence-based science and pedagogy. This can be accommodated by giving teachers designated time and support to find and develop materials for their individual contexts. Additionally, there is often a perception that there is little time to cover the topic amidst those required by state testing. By making direct and explicit connections between the GCC concepts and the standards, especially those that could be seen as proximally related, may all but eliminate this issue.

Fostering both Pedagogical and Academic Content Knowledge

In order for the widespread and successful implementation of any new curriculum or methodologies, teachers need a framework and experience in the proposed style of teaching and learning (Derman et al., 2016; Li et al., 2021). This includes both academic content knowledge (ACK), or standards-based knowledge of the subject area, and pedagogical content knowledge (PCK), or knowledge about how to teach the academic content (Monet, 2006; Monet & Etkina, 2008; Teed & Franco, 2014). As such, it is imperative that teachers receive extensive scaffolding before, during, and after their implementation of new practices. The translation to actual implementation of practices in the classroom can be facilitated by including dedicated time to work with peers and facilitators to create and curate curricular resources that align with participants' specific context and support the ACK and PCK developed during the PD. Any PD intending to create a lasting change will need to account for all these moving parts.

Purpose and Significance of the Study

The goals of this project are four-fold. The first is to develop a PD program for in-service secondary teachers that tackles climate change science-related academic and pedagogical content knowledge. Secondly, we evaluate how the PD program impacts teachers' academic and pedagogical content knowledge. Thirdly, we address variations in participants' self-efficacy toward teaching climate change. The final goal of this study is to provide a cursory assessment of how teachers translate PD into classroom practices.

This project created a climate science PD that is directly influenced by current literature and evaluated the program's impacts to expound upon three key questions:

1. How does the program influence teachers' self-efficacy toward teaching climate change?
2. How does participation in the program impact teachers' understanding of climate change science (ACK)?
3. What instructional practices related to climate change education do teachers try to adopt during and after the program (PCK)?

This study serves to address the urgent societal needs for climate change literacy. In order to empower teachers to engage with scientific data inside and outside of their classroom, we sought to develop a baseline understanding of the science behind earth's systems and their interactions, and how that relates directly to climate science. Through the use of both modeling and explicit instruction, the PD program also addressed pedagogical concepts and concerns. This study contributes to the growing body of literature on effective climate change-related PD and pedagogy and provides guidance for improving these programs.

Theoretical Framework

Hot Topics in Earth Science (HTES) was developed with several structural focuses in mind including ideas about storyline development, inquiry-based education, place-based education, and anticipating and adapting to the specific needs of the teachers being brought in.

Constructivism, Contextualization, and Inquiry

One of John Dewey's overarching themes for the role of education was to create independent and democratic students who sought to understand the world around them from their own contexts. Dewey discussed and popularized the idea of "practical work" as an essential part of truly learning (Dewey, 1904, 1997a, 1997b). He also emphasized the importance of contextualized learning, rather than disjointed facts. In his words, schools had reduced the full picture of a phenomenon to studying "the flower apart from the plant; the plant apart from the soil, air, and light in which and through which it lives" (Dewey, 1997a, p. 250). This "learning-by-doing" method provided the "so what" or "hands-on" approach that sits at the forefront of the theory behind inquiry and laboratory-based teaching in the modern-day. However, this has devolved, commonly, into cookie-cutter laboratory exercises designed to model a small portion of a system that meets associated standards. In contrast, this study attempts to retain the spirit of the full picture by promoting the use and manipulation of real data, emphasizing the connections between concepts, and encouraging participants to further connect these concepts and practices to their own teaching standards and lesson plans.

Acknowledging and Empowering Varying Epistemologies

GCC will eventually impact everyone (Calvin et al., 2023). However, the most affected groups are, and will continue to be, those from marginalized communities (Calvin et al., 2023; Pellow, 2017; Tessum et al., 2019). As such, understanding only the science behind the causes and impacts of GCC provides an incomplete picture and must be contextualized within an understanding of social inequities. Paulo Freire viewed education as an opportunity for the development of critical consciousness within the individual, wherein the oppressed party acknowledges their place of oppression and develops the skills and understanding to liberate themselves (Freire, 2000). While their views of the role of the teacher were slightly different, the concept of developing self-determination and critical thinking skills within an individual's context (or place) was important to both Dewey and Freire.

Addressing social inequities in the classroom, especially the science classroom, can be difficult for teachers for a variety of reasons. GCC has crucial social components that must be addressed in classrooms, as it is equally as important for students to connect the science with the broader impacts and implications to develop informed conclusions. Climate change as a topic poses an ideal opportunity to fully utilize diverse funds of knowledge, or strategic and cultural resources (Velez-Ibanez & Greenberg, 1992). Drawing from students' lived experiences can provide a wealth of material for exploring GCC-related concepts by introducing concepts in a more personal, relatable manner or context.

The Role of Place in Developing Environmental Identity

Sense of place is influenced by a variety of factors but can be summarized by two general approaches: experiential and instructional (Kudryavtsev, Stedman, and Krasny, 2012).

Experiential approaches draw from the ideas of hands-on experiences and deriving meaning from first-hand experience in a physical space. This idea aligns with previous literature, which indicated that "long-term, frequent or positive experiences in places, and active engagement with places," commonly involving unstructured interaction as a component, can nurture a sense of place in the context of environmental science (Kudryavtsev, Stedman, and Krasny, 2012, p. 239). The second approach is instructional, which is designed to convey meaning that may not be realized strictly through interaction with the environment. This could include discussions, probing questions, or pieces of media and strategies of instruction, negotiation, and interpretation. Emphasis is placed on both the teacher's role in guiding the direction of the meaning-making and the student's assistance in constructing and modifying meaning surrounding the area of focus. However, there is a third commonly used option, the combined approach, which melds both instructional and experiential approaches (Kudryavtsev, Stedman, and Krasny, 2012).

Outdoor, nature, and place-based education are growing in popularity as ways for students to engage with their community, connect with the place they live, and learn or apply information that would normally not extend past the classroom walls (Lynch & Mannion, 2021; Smith, 2002; Sobel, 2013). Outdoor education may be a prime medium for facilitating GCC learning due to its accessibility (outside is everywhere) and the inherent relationship between the natural world and how it is changing through anthropogenic actions and the associated impacts on the Earth System. Multiple studies show a correlation between place attachment, or emotional connection, and pro-environmental perspectives (Kudryavtsev, Stedman, and Krasny, 2012). Young, Carsten Conner, & Pettit's (2020) study found that direct interaction with climate change-impacted areas can lead to environmental identity shifts in early adolescent age girls.

Arbuthnott et al. (2022) found that, while emotional improvements can be made without direct contact with nature, it does not promote emotional well-being as well as time in nature. Additionally, they found that programming in nature improves feelings of nature connectedness that does not occur with similar online programming.

However, place attachment is not the only driving force for pro-environmental perspectives. Howell and Allen (2019) found that while outdoor experiences constitute a significant formative influence on some respondents' pro-environmental attitudes (those who made life changes for environmental reasons and actively communicated climate science to general audiences), it was not universal to all of their participants. Common factors that contributed to these attitudes were work, education, the media, people, and groups/organizations. Social justice concerns were mentioned more often than biospheric concerns, with participants citing altruistic and biospheric values as equal in driving their chosen path.

Scope and Limitations

This study took place at a higher education institution in central Oklahoma. To help address concerns about attendance, PD participants were recruited by contacting all in-service middle and secondary science teachers working at public schools in the districts immediate surrounding the location of the PD. As a part of further considerations given to encourage attendance, participants were offered a stipend for each day of attendance and light refreshments were provided. Those who completed the program also received a certificate to document the associated credits for their respective workplaces to include towards their required PD hours. Each iteration of the PD took place for two weeks over the summer, one in 2023 and the second in 2024, and was held Monday through Friday from 8:30am to noon. All PD attendees were invited to participate in the study; however study participation was not a requirement for PD attendance or stipends.

There are several limitations to this study. First and foremost is the small sample size (Y1 n=9, Y2 n=10). Participants self-selected to attend this program, with some choosing to attend both years. Minimal follow-up in Year 1 and no follow up in Year 2 prevent us from drawing conclusions about the long-term impacts of the program. Content also varied from Year 1 to Year 2. As such, this data should not be considered generalizable.

Organization of the Thesis

This thesis is subdivided into three additional chapters. Chapter 2 is modeled after a practitioner-style discussion of the design of each of the two years of the HTES PD program. Its Appendix also contains examples of the products produced by participants. The qualitative and quantitative empirical findings of HTES are discussed in Chapter 3. Finally, Chapter 4 summarizes the findings, revisits the initial design to suggest room for improvements, and describes potential paths for future work.

Ch 2. Developing and Implementing *Hot Topics in Earth Science*, a Climate (Change) Science Professional Development Program for Secondary Science Teachers

Introduction

Motivations: The State of Climate (Change) Science Education in Oklahoma

In the state of Oklahoma, the majority (~60%) of the population accepts that climate change is happening (which is ~10% below the national average of 72%), however well under 50% attribute climate change to human activity (Howe et al., 2015; Marlon et al., 2022). Energy sector employment in Oklahoma is three times the national average (The 2019 U.S. Energy & Employment Report, 2019) and Oklahoma is arguably one of the major sites of misinformation and disinformation campaigns about anthropogenic CO_2 emissions, extending to the point of climate science denialism (Colston & Ivey, 2015). Curricular resources highlighting climate science are limited for Oklahoma secondary teachers, and those that do exist are doing little to address disinformation about anthropogenic CO_2 emissions and climate denialism. One example includes teacher PD and curricular resources that use illustrated children's books, virtual field trips, and a petroleum-themed mascot all supported financially through the state's oil and gas industry (Oklahoma Energy Resources Board, or OERB). In 2019, 98 percent of OK school districts had OERB-trained teachers (OERB Annual Report: Building a Better Oklahoma, 2019).

(Perceived) Barriers to Teaching Global Climate Change (GCC)

Global Climate Change (GCC) is a complex and multifaceted topic, one that many teachers are not confident about teaching (Li et al., 2021). The primary concern cited by teachers is a lack of time (Ennes et al., 2021). This can be considered time in the form of physical time, as teachers are often overworked or lack flexibility when accommodating standardized tests and covering the required material. When paired with a lack of funding and perceived lack of support, as well as related but non-explicit standards, GCC is easily relegated to a single class period or activity, if it is covered at all (*Introduction to the OKScience Framework*, n.d.). However, GCC as a topic is highly interdisciplinary and, as such, can be addressed while discussing a variety of standards both in and outside of the sciences. It is merely a matter of taking the time to draw more explicit connections between source material and climate change concepts.

Ennes et al. (2021) suggested that, in areas with higher prevalence of GCC denialism, efforts to reduce barriers to joining GCC-related PDs are even more important. They also suggested obtaining support from participant's school administration, and join others (e.g. Hestness et al., 2014) in emphasizing the importance of centering place when teaching GCC content by appealing to local contexts. Hestness et al. (2014) made the argument that any GCC PD should include "quality standards-aligned curricular resources…especially those that integrate technology."

Academic and Pedagogical Content Knowledge

Climate change content is slightly different from the average content discussed in PD. In particular, it easily fits into social, political, scientific, and emotional discussion points. Primary methods for introducing climate change-related topics can be summarized by four overarching strategies (Monroe et al., 2017, pg.11):

1. [Using] deliberative discussion to help learners better understand their own and others' viewpoints and knowledge about climate change.
2. [Giving learners] the opportunity to interact with scientists and to experience the scientific process for themselves.

3. [Designing programs to] uncover and address misconceptions about climate change.
4. [Engaging learners] in designing and implementing school or community projects to address some aspect of climate change.

While implementing these strategies is useful for the facilitators of PD, it is also important to convey to the teachers who will go on to convey information to their students. These tactics utilize both academic content knowledge (ACK), or standards-based knowledge of the subject area, and pedagogical content knowledge (PCK), or knowledge about how to teach the academic content (Monet, 2006; Monet & Etkina, 2008; Teed & Franco, 2014) to create a broad spectrum of understanding.

Conceptual Frameworks and Design Choices

Widespread and successful implementation of any new curriculum or methodologies requires teachers to have a framework and experience in the proposed style of teaching and learning (Derman et al., 2016; Li et al., 2021). As such, it is imperative that teachers receive extensive scaffolding before, during, and after their implementation of new practices for both ACK and PCK. "Hot Topics in Earth Science" was developed with several structural foci in mind; including ideas about storyline development, inquiry-based education, place-based education, and anticipating and adapting to the specific needs of the teachers taking part in the program. The goal was to create PD that was effective in actually changing teacher practices, by facilitating repeated and long-term exposure to content-specific material (Hauck, 2012; Luft & Hewson, 2014) through a participant-centered experience (Loucks-Horsley et al., 2009).

Program Overview

Facilitator Background

Hot Topics in Earth Science was designed with attention to two separate but essential content components: academic content knowledge and pedagogical content knowledge, each facilitated by a subject matter expert. The PCK lessons were facilitated by an associate professor of science education. The ACK was presented by a graduate student in Science Education (M.Ed.) and Geology (M.S.) with an undergraduate background in geology, with an effort to teach the content by modeling the pedagogies. Additional support during the program was provided by three doctoral students in science education during Y1, each of whom has multiple years of experience in local secondary schools, and by one returning doctoral student in Y2.

Timeline

HTES, from initial literature review to the final day of the PD, took two years to complete (see Table 3).

Table 3.

Timeline Of Professional Development Program Creation and Implementation

Tasks	Description	Start Date	End Date
Initial Literature Review	Review literature related to the following topics and their intersection: teaching climate change, professional development programs, place-based education, secondary science teachers, Oklahoma state science standards	09/2022	05/2023
Year 1 Curriculum Planning and Development	Develop standards-based climate science and pedagogical lessons	01/2023	07/2023
Year 1 Recruitment	Distribute posters and send recruitment emails to all secondary science teachers in the surrounding districts	03/2023	06/2023
Year 1 PD	2-week (10 day) professional development program	07/2023	07/2023
Year 1 Semestral Follow Ups	Schedule monthly meetings to provide further support and check-ins	09/2023	05/2024
Follow Up Literature Review	Review literature using the same criteria with additional attention spent on teaching deep time and abstract concepts	09/2023	12/2023
Year 2 Curriculum Planning and Development	Develop standards-based climate science and pedagogical lessons	01/2024	06/2024
Year 2 Recruitment	Distribute posters and send recruitment emails to all secondary science teachers in the surrounding districts	03/2024	06/2024
Year 2 PD	2-week (9 day) professional development program	07/2024	07/2024

Participant Recruitment Methods

Emails were distributed to every secondary science teacher in the districts immediately surrounding the location of the PD in the hopes of maintaining attendance by reducing travel times. Several emails were sent over the course of the spring semester before each summer PD took place. Fliers were also posted to the university's graduate college of education. To further incentivize participation, monetary compensation was offered for each day of attendance; regardless of participation in the associated research study.

General Considerations

This PD was targeted towards in-service secondary science teachers in the state of Oklahoma, primarily those who teach earth or environmental science standards in their classrooms. Teachers who chose to participate in the PD all self-selected to take part in it, and data about their motivations for participating was not collected. Generally, each day of the PD included a set schedule to help facilitate the completion of the program's goals.

Program Goals

While developing this PD, the organizers had several goals in mind, which can be summarized as:

1. Improve self-efficacy with regard to climate change science content and teaching it
2. Curate resources that are contextually applicable
3. Build community among teachers in similar subject areas

Improving Self-Efficacy

To improve self-efficacy (SE) in participants, the developers chose to spend significant time focusing not only on ACK, but also in developing participants' PCK. This included covering more broad-scale teaching strategies and concepts such as assessment (Dolfing et al., 2021; Gess-Newsome et al., 2019; Hauck, 2012; Holden et al., n.d.; Kelley et al., 2020) in addition to more earth science (Monet, 2006; Monet & Etkina, 2008) and climate change specific methodologies (Hestness et al., 2014; Li et al., 2021; Shea et al., 2016). Many of the practices discussed were modeled during the ACK-focused portion of the PD as examples of how to apply the PCK portion. Participants were also given designated time, usually with optional guiding questions, to share strategies with one another. Each day, the teachers also took part in a reflection of what topics were discussed and how they could apply these concepts to their context.

Curate Contextually Applicable Resources

Facilitators sought out a variety of resources that may be useful to the demographic of participants (in-service, secondary science teachers) with the goal of curating contextually applicable resources. This included finding or modifying existing activities and assignments from external sources such as those created by federal agencies (ex. National Aeronautics and Space Administration or NASA). Participants were also given opportunities to connect with nearby university professors and the Oklahoma Geological Survey to learn about their available resources and funding opportunities. Facilitators also sought out and promoted opportunities for grants and funding on both the local and national scale. Finally, participants were given designated time each day to modify and develop the lessons used in their personal classroom with input from their peers and facilitators.

Build Community

Each day during the PD, participants were given “coffee and conversation” time to chat about a related guiding question with their peers. Participants were also assigned to tables based on their grade levels, separating high school and middle school teachers and grouping teachers roughly based on their district (to provide access to those with corresponding curricula). Table groups also frequently interacted to provide each other with support and feedback on activities. Along with building community with those who share their subject areas, teachers were given opportunities to connect with local organizations and individuals involved in the content areas.

General Daily Formatting

Each day was divided into four sections designed to explicitly address both the goals of the PD and teacher's reported concerns or barriers (see Table 4).

Table 4.

Approximate Daily Professional Development Schedule

Activity	Time	Goals Addressed	(Perceived) Barriers Addressed
Coffee and conversation	09:00-09:30	Community	Lack of support
Academic content knowledge (ACK)	09:30-10:30	Self-efficacy Resources	Scientific complexity Lack of support
Pedagogical content knowledge (PCK)	10:30-11:30	Self-efficacy Resources	Lack of support Time
Context-specific product design	11:30-12:00	Self-efficacy Resources Community	Lack of support Time

The Role of the Facilitator

Facilitators of the program took care to make all materials readily available and to prepare contingencies for all activities. From pencils and notebooks to tablets, participants only needed to show up in order to take part in the PD. Contingencies included those that are normally expected in any subject (i.e. potential and alternatives for poor weather, technical issues, misplaced supplies) but were also made to account for problems unique to topics that have political and emotional connotations. Facilitators familiarized themselves with literature surrounding topics such as how to approach potentially emotionally- or politically charged subjects and combatting mis- and disinformation in the classroom. They were prepared for the potential to encounter significant resistance or outright belligerence from some participants and had plans in place with co-facilitators on how to best handle any potential tensions that arise.

In particular, during these PDs, facilitators came into each lesson with the goal of presenting data, aiding participants in understanding and interpreting the data, and having participants discuss the implications of the data. Rather than attempting to sway participants' *beliefs* about how broad-scale society should respond to climate change, our goal was to present *scientific evidence* that: climate change exists, it is anthropogenic in origin, and—while it impacts everyone—disproportionately impacts underserved and marginalized communities. We also sought to emphasize the disparities between primary polluters and contributors to anthropogenic global climate change, and the populations that face the greatest consequences. However, facilitators were conscious of the potential for inducing climate anxiety (Ginsburg & Audley, 2020) in participants and, as such, tried to balance the causes and effects of climate change with stories of resilience, hope, mitigation, and adaptation efforts. The ultimate goal was for participants to leave the room with a broader background in the content, new or refined methods of teaching the content, and resources and tools that they can use in their individual contexts.

Year 1-Earth's Systems in Recent History

The first year's PD took place over two weeks in the summer of 2023 and focused on Earth's systems in recent (human) history. Each day focused on a related science topic and modeled skills from the corresponding pedagogical lesson.

Participants

Nine participants (referred to using pseudonyms) took part in the first PD. Five identified as female and four identified as male. Experience ranged from those with 0-2 years of teaching to veterans in the field with 21+ years. Nearly half of the participants (4/9) identified themselves as alternatively certified. Three of the participants taught at a high school level, five taught at a middle school level, and one taught at the elementary level.

Lesson Descriptions and Student Work

Table 5 displays the Y1 daily topics of discussion and some of the tasks that students undertook. Participant artifacts (journals, models, lesson plans, etc.) varied with each lesson but were digitized for our records and returned to their creators. In addition, each participant was asked to write reflections of the daily activities. Examples of these products and images of students partaking in activities can be found in Appendix A.

Table 5.

Year 1 Itinerary

Day	Topics	ACK	PCK
1	Introduction, Pre-Assessment, and Goal-setting	Introductions of Participants and Staff Pre-survey and Initial Model of Earth's Systems	Rapid Fire Earth Science Planning Success & Challenges of Earth Science Teaching Needs, Wants, & Wishes from PD
2	Introducing the Earth's Systems	The Year Without Summer: an Example of Rapid Climate Change Revisiting the data: searching for systems interactions	Teaching Science with Anchoring Phenomena: Finding Phenomena for Your Context
3	Water on Earth	Where is Earth's Water?	Teaching Science with Real Data: Sourcing Data
4	Water on Earth	Introducing Creativity to the Hydrologic Cycle: Unconventional Assessments	Using Models for Science Teaching, Learning, & Assessment
5	Weather and Climate	Why Aren't We Freezing Right Now? An Introduction to Atmospheric Chemistry and Orders of Magnitude	Using Puzzling Questions for Science Instruction: Preparing and Using Storylines
6	Weather and Climate	Systems Interactions: Earth's Energy Budget, Feedback Loops, and Albedo	Translating Big Ideas into Lessons

7	Global Climate Change	Carbon Cycle & Climate Change	Scientific Literacy in the Classroom: Finding, Interpreting, and Using Real Scientific Literature
8	Global Climate Change	Carbon Cycle Breakout Boxes	Designing Play-Based Learning Experiences and Practice with Scaffolding Students
9	Human Interactions	The Modified Wedges Game: Climate Change, Carbon, and Mitigation • Modified from Princeton's Climate Mitigation Initiative (Johnson et al., 2021)	Making Evidence-Based Decisions
10	Post-Assessment and Curriculum Product	Post Survey & Final Model Product Finalization	Successes & Challenges (personal only) Goal Setting for the Semester

Semestral Activities

At the end of Y1, participants were asked to set personal goals to implement in their classroom. Goals varied greatly between participants: some chose to focus primarily on classroom management strategies such as encouraging student engagement, while others focused on integrating Hot Topics ideas and activities into their own curriculum. During the semesters between Y1 and Y2 (fall of 2023 and spring of 2024), the Hot Topics facilitators hosted a series of short, 1-day paid PDs with a variety of topics (see Table 6) that also functioned as check-ins with the participants. The motivation behind this was to continuously support the teachers during the implementation period and maintain the community developed during the initial PD. While three of these took place on Saturdays, the facilitators worked with teachers' principals to obtain paid professional days for participation in Friday PDs for the two other occurrances, emphasizing a willingness to support their teachers in their pursuits.

Table 6.

Semestral Meeting Itinerary

Month	Topics	Activity Brief
09/2023	Goal setting + Geoengineering	Review and reflect on the goals set during the last day of the summer PD. Research and debate/discuss the implications of proposed geoengineering projects from an Earth Systems perspective
10/2023	Current earth science research	Poster session and educational path panel with geoscience undergraduate and graduate students
01/2024	Local organizations: resources and outreach efforts	A representative from the Oklahoma Geologic Survey and Oklahoma Geologic Foundation came to discuss their programming and opportunities
03/2024	National Weather Center facilities tour	Guided tour of the National Weather Center and discussion of educator resources from outreach faculty
05/2024	Presentations	Participants present on the successes and challenges of implementing the goals and resources they developed during the summer PD

These PD days addressed various topics, from making connections between science fiction and engineering using geoengineering, to conversations with representatives from state and federal organizations about local resource availability. While they were all well received by participants, the teachers seemed especially excited to speak with students and representatives from other organizations. In addition to the topics designated for that particular session, the semestral PD days were also used as check-ins for the teachers to reflect on the progress they were making towards the goal they had set at the end of the summer PD. These goals ranged from general ("student engagement") to highly specific ("interpretation and creation of data tables, maps, & graphs through Unit 6: Earth Resources & Human Impacts").

Year 2-Earth's Systems in Deep Time: Vignettes on Mass Extinctions, Climate Change, and Relationships to the Modern World

The second iteration of the 2-week PD took place in the summer of 2024 and covered topics of Earth's systems and climate change in the context of deep (also referred to as "geologic") time.

Modifications After Year 1

Several modifications were made after the first year's PD. With respect to content; the topics shifted to longer timescales, and were designed to work with the previous year's materials without alienating new participants. Adjustments were also made to refine the "place" in place-based education to Oklahoma-specific as opposed to broader areas such as the United States. This included opportunities to take a field trip to a local National Wildlife Refuge to explore the geology, ecology, and system interactions with a local professor of geosciences.

Participants

Ten participants (referred to using pseudonyms) took part in the second year of the PD, which included seven returning from the previous year. Six identified as female and four identified as male. Experience ranged from those with zero to two years of teaching to 21+ years. Three participants identified themselves as alternatively certified. There was a relatively even split in terms of grades taught, with four teaching high school and six teaching middle school.

Lesson Descriptions and Student Work

Y2 lessons were designed to convey similar concepts as those covered in Y1 but in a different context so as to create a unique experience for returning and new participants alike. Rather than attempting to condense 4.6 billion years of Earth's history into a 2-week PD, the Y2 lessons (see Figure 7) focused on providing a brief and broad overview of geologic time before shifting the focus to specific periods in geologic time and how Earth's systems interacted during those periods. Mass extinctions were chosen to present the great variability of Earth's past climate, and to encourage the teachers to apply their broader knowledge of Earth's systems and their interactions to different situations to parse cause-and-effect relationships and draw connections to the modern.

Table 7.

Year 2 Itinerary

Day	Topics	ACK	PCK
1	Introduction, Pre-Assessment, and Goal-setting	Introductions of Participants and Staff Pre-survey and Initial Model of Earth's Systems	Rapid Fire Earth Science Planning Success & Challenges of Earth Science Teaching PD Goals
2	Introducing Earth's Systems and Geologic Time	Introducing Earth's Systems Putting Geologic Time into Perspective: the Time Scale Nature Journaling through Human and Geologic Time	Introduction to Place- and Nature-Based Education
3	Place and Nature-based Education	Field Trip Preparations	Place- and Nature-Based Education Continued
4	Field Trip	Geologic History of Oklahoma: Interpreting the Rock and the Landscape	Using the World Around You: Nature Journaling and Teaching Outdoors
5	Day off		

6	Introducing Interdisciplinarity in the Classroom	Introduction to Proxy Data: Interdisciplinarity in the Earth Sciences	Analyzing the Standards: Exploring and Connecting Other Disciplines
7	Applying Modeling to Case Studies	Using A Mass Extinction as a Case Study to Move Beyond Modern Earth System Models	Using Models to Evaluate and Build Upon Current Understandings
8	Assessments and Case Studies	Evaluating Understandings of Earth's Systems Interactions through the Application of Mass Extinction Case Studies	Non-Traditional Assessment
9	Addressing Politically and Emotionally Charged Topics: What Can it Look Like?	Summarizing and Utilizing the International Panel on Climate Change's Assessment	Addressing Politically and Emotionally Charged Topics
10	Post-Assessment and Curriculum Product	Post Survey & Final Model Product Finalization	Successes & Challenges (personal only) Goal Setting for the Semester

Outcomes and Key Considerations

Outcomes

The goals of this PD were as follows: 1) to improve self-efficacy with regard to climate change science content and the teaching of it, 2) to curate resources that are contextually applicable to participants, and 3) to build community among teachers in similar subject areas. As a whole, the program was well-received and successful in accomplishing its initial goals. The teachers who participated showed significant improvements in both their ACK and SE scores in Y1 and Y2. As a direct result of one of the semestral meetings; a participant learned about, applied for, and received a monetary grant for classroom supplies. Additionally, two participants decided to take steps to become involved with the statewide seismic network and obtained relevant equipment for their classrooms. Finally, teachers from across districts and grade levels were able to trade stories and strategies while learning more about how different contexts broach the same topics. This also gave teachers the time to delve deeper into their own standards and the interconnections between them and the standards in other grade levels.

Considerations

Climate change can be a politically- and emotionally- charged topic. Accordingly, explaining concepts in an evidence-based, data-driven manner that focuses only on what the information is saying without extrapolating to potential solutions is one method of tackling these issues. Having students interpret real scientific data or figures primarily on their own and with teacher guidance can help by encouraging students to develop their own evidence-based explanations and meaning to the data, rather than causing them to feel like specific views are being imposed upon them. Allowing participants time to consider the implications of the data alone and develop their own ideas before sharing can allow for more productive and less reactive discussions.

Adaptations and Final Thoughts

This program was originally designed with Oklahoma teachers in mind, using Oklahoma state science standards (OAS-S) as a guideline. However, OAS-S derives its standards primarily from NGSS standards. Thus, our activities, topics, and interdisciplinary style of PD and content is generalizable to any NGSS framework state. That said, the experience of this group was greatly influenced by several key factors that should be considered by anyone desiring to adapt this approach. Proximity and connections to state and federal institutions, as well as scientists eager for education outreach opportunities was particularly convenient for developing the semestral activities and field trips. Several of our activities attempted to emphasize place as a key medium for learning. As such, any adaptations should account for the geographic, historical, and other factors that may influence their particular context. These should be seen as opportunities for enrichment and customizability of the activities.

For those seeking to adapt our approach to PD, we recommend one change to the formatting: continue to consistently present both ACK and PCK throughout the "off-season" semester. We observed slight drops in both ACK and SE scores between the Y1 and Y2 PDs. While the teachers decidedly benefitted from the semestral activities, the programming was primarily oriented towards networking and focused less on the content and specific teaching techniques even though we maintained the strategy-sharing style discussions between participants. They also served as check-ins towards the goals set by the participants during the final summer PD day. This had mixed results as there was a marked reduction in teacher participation and a wide variety of "goals" with varying degrees of achievability. In our experience, those with concrete goals (i.e. "interpretation and creation of data tables, maps, & graphs through Unit 6: Earth Resources & Human Impacts," or "implementing Hot Topics ideas and activities in each class") were more likely to remember them and make significant strides towards achieving them.

Overall, we believe that the Hot Topics in Earth Science PD opened new doors for each of our teacher participants. While their individual experiences may have been vastly different due to their specific contexts, each participant left the PD with something new; whether that was new strategies and techniques for teaching content, new ideas about assessments and activities, a greater understanding of the world around them and the Earth's systems, or connections to the broader field of earth sciences.

Ch 3. Hot Topics in Earth Science: Evaluating Two Years of Global Climate Change Focused Professional Development for In-Service Science Teachers

Background

Anthropogenic Global Climate Change (GCC) is a complex, interdisciplinary issue that will ultimately affect everyone on the planet. The window to address, mitigate, and adapt to these changes is rapidly closing, and in many ways, has already closed without significant progress in critical areas such as policy reform and consumption patterns among major contributors (Millar et al., 2017). The Intergovernmental Panel on Climate Change (IPCC) Assessment Report underscores the urgency of the crisis and the pressing need for mitigation efforts (Calvin et al., 2023). However, despite of scientific consensus on the topic, widespread misinformation and disinformation campaigns have severely impacted public and policymaker understanding of GCC, its causes, and its consequences (Howe et al., 2015; Lewandowsky, 2021; Marlon et al., 2022; Oreskes, 2004; Oreskes & Conway, 2011; Treen et al., 2020).

GCC Understanding and Education in Context

In Oklahoma, around 60% of residents acknowledge climate change, approximately 10% below the national average of 72%, while fewer than 50% attribute it to human activity (Howe et al., 2015; Marlon et al., 2022). Although these numbers are likely influenced by various of factors, it is important to note that the state's energy sector employment is three times the national average (The 2019 U.S. Energy & Employment Report, 2019) and has been a hotbed for misinformation and climate science denialism (Colston & Ivey, 2015; Oreskes, 2004; Oreskes & Conway, 2011).

Although the Next Generation Science Standards (NGSS) emphasize climate education (NGSS Lead States, 2013), Oklahoma has historically struggled to meet these standards (Colston

& Ivey, 2015). The state's current science standards (Oklahoma Academic Standards for Science, OAS-S) (*Introduction to the OKScience Framework*, n.d.), adopted in 2020 and first evaluated in 2022-2023, incorporate NGSS language but often in a less explicit manner (MAKING THE GRADE? How State Public School Science Standards Address Climate Change, 2020). Additionally, educational resources for teaching climate science in Oklahoma are limited, with many influenced by the oil and gas industry. For example, the Oklahoma Energy Resources Board (OERB) funds teacher training and curricular materials, including children’s books, virtual field trips, and a petroleum-themed mascot. In 2019, 98% of Oklahoma school districts had OERB-trained teachers, with the organization providing stipends and grants to schools hosting its workshops (OERB Annual Report: Building a Better Oklahoma, 2019).

The Problem from Teachers’ Perspectives

Global Climate Change (GCC) is a complex subject that many teachers feel unprepared to teach (Li et al., 2021). Limited time and funding, perceived lack of support, and vague standards often reduce GCC education to a single lesson or activity (*Introduction to the OKScience Framework*, n.d.; MAKING THE GRADE? How State Public School Science Standards Address Climate Change, 2020). However, GCC is inherently interdisciplinary and, with the right support system, can be integrated across various subjects. For effective implementation of new curricula or teaching methods, teachers need structured frameworks and hands-on experience (Derman et al., 2016; Li et al., 2021). This includes both academic content knowledge (ACK) and pedagogical content knowledge (PCK), which encompass subject-specific teaching strategies (Herranen & Aksela, 2024; Monet, n.d.; Monet & Etkina, 2008; Teed & Franco, 2014). To ensure lasting change, any professional development (PD) attempting to tackle topics surrounding climate change must consider all of these aspects and provide support before, during, and after implementation.

Study Goals and Significance

Hot Topics in Earth Science (HTES) is a teacher PD designed for in-service secondary science teachers (Grades 6-12) and aims to address the pressing need for climate change literacy by equipping teachers with the skills to engage with scientific data both in and out of the classroom. The program focused on building a foundational understanding of Earth's systems, their interactions, and their direct connection to climate science. Through a combination of modeling and explicit instruction, the PD also tackled key pedagogical concepts and challenges. This research adds to the expanding body of literature on effective climate change-focused PD and pedagogy, offering insights for enhancing these programs. The goal of this study is to analyze how participation in HTES impacted individuals' climate change education-related self-efficacy (SE), ACK, and PCK.

Participants and Data Sources

Participant Recruitment and Demographics

This study was conducted at a higher education institution in central Oklahoma, with facilitators from both science education and geoscience backgrounds. Participants for the PD program were recruited by reaching out via email to all in-service secondary science teachers employed in public schools within the districts surrounding the PD location. The program was offered over two weeks during the summer, with one session held in 2023 and another in 2024, running Monday through Friday from 8:30 AM to noon. The content varied slightly between years, with the first year (Y1) discussing Earth's systems and interactions on a human time scale and the second year (Y2) covering Earth's systems through geologic time.

During the consenting process, each participant chose a unique identifier, then was assigned a pseudonym. Additional demographic data for each year can be found in Appendix B. Both Year 1 (Y1) and Year 2 (Y2) participants (n=9 and n=10, respectively) had a broad range of ages and classroom experience but were evenly split along gender identity and grade levels (see Table 8). One difference between the overall demographics was certification status (standard or alternative certification), with Y1 showing a more even split and Y2 having a majority with standard certification. Participants varied from Y1 to Y2, but many (n=7) were repeat attendees, as the content varied between years.

Table 8.

Hot Topics in Earth Science Participant Summary

	Year 1	Year 2
Number of participants (n)	9	10
Repeat participants	n/a	7
Gender identity	Male: 4 Female: 5	Male: 4 Female: 6
Age	Min: < 25 Max: 50-59	Min: < 25 Max: 50-59
Teaching experience	Min: 0-2 Max: 21+	Min: 0-2 Max: 21+
Certification status	Standard: 5 Alternative: 4	Standard: 7 Alternative: 3
Grade level	Elementary: 1 Middle: 5 High: 3	Middle: 6 High: 4

Data Sources

Pre- and post-tests were given to evaluate self-efficacy (SE) and academic content knowledge (ACK). The Climate Change Education Teacher Efficacy Belief Instrument

(CCTEBI) (Li et al., 2021) was utilized as a measure of SE. The CCTEBI (see Appendix C) was created by combining key components of the Self-Efficacy Teaching and Knowledge Instrument for Science Teachers-Revised (SETAKIST-R) (Pruski et al., 2013) and the Environmental Education Teacher Efficacy Belief Instrument (EETEBI) (Moseley et al., 2016). ACK questions were free response and were derived from the Oklahoma Academic Standards for Science (OAS-S). Responses were graded by several research assistants using a pre-designed rubric (see Appendix D) and any variations in assigned grades were discussed and debated by the research team until consensus was reached. Grading was only done for internal data collection and participants were not informed of their assigned scores.

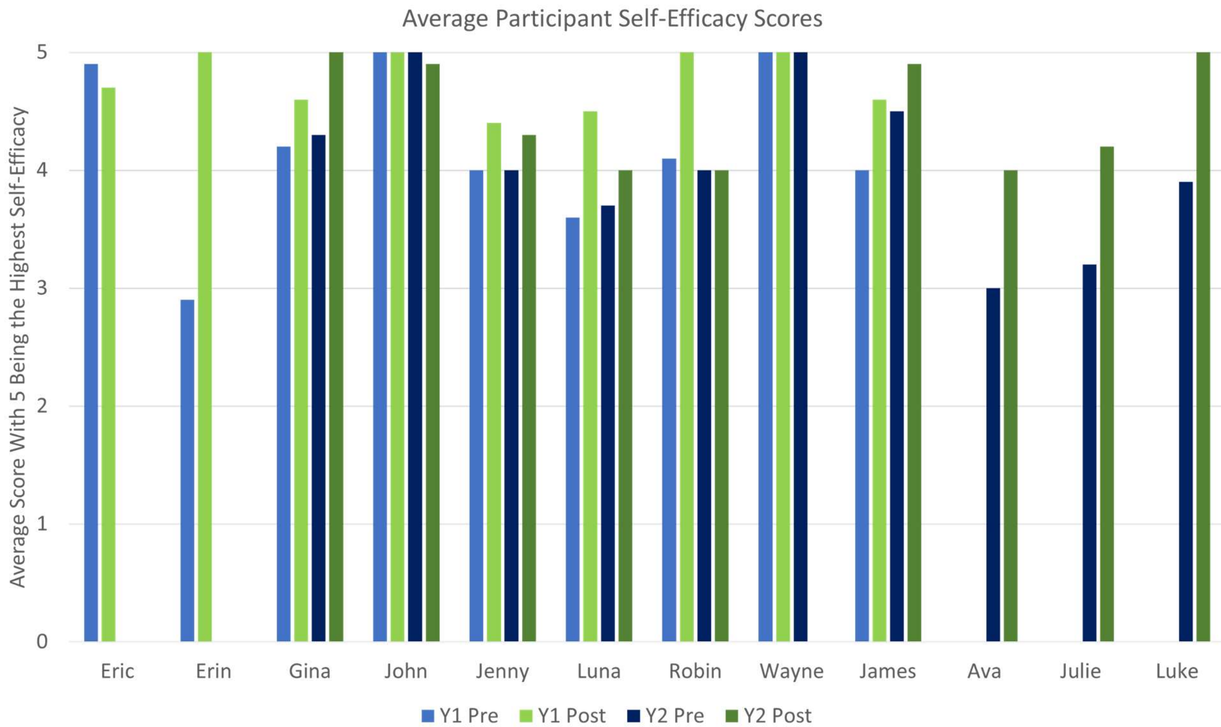
Results

Self-Efficacy (SE)

SE was measured through a series of statements from the CCTEBI and rated using a Likert scale of one to five, with five being the highest (see Figure 1). Paired t-tests on participant's mean self-efficacy scores from pre- to post-test showed a statistically significant increase in Y1 means from 4.19 with a standard deviation (SD) of 0.7 to a mean of 4.76 (SD=0.2) with t=2.4 and p=0.040. The standard deviation of differences (SDD) of SE in Y1 is 0.69. Y2 SE values also showed a statistically significant increase from 3.96 (SD=0.6) to 4.48 (SD=0.5) with t=3.5 and p=0.008. The SDD was 0.45. However, between Y1's post-test and Y2's pre-test, participants that attended both Y1 and Y2 displayed a statistically significant decrease in mean SE from 4.73 (SD= 0.26) to 4.35 (SD=0.51) with p=0.047 and SDD=0.39.

Figure 1.

Average Participant Self-Efficacy Scores from Y1 Pre-Test to Y2 Post-Test.



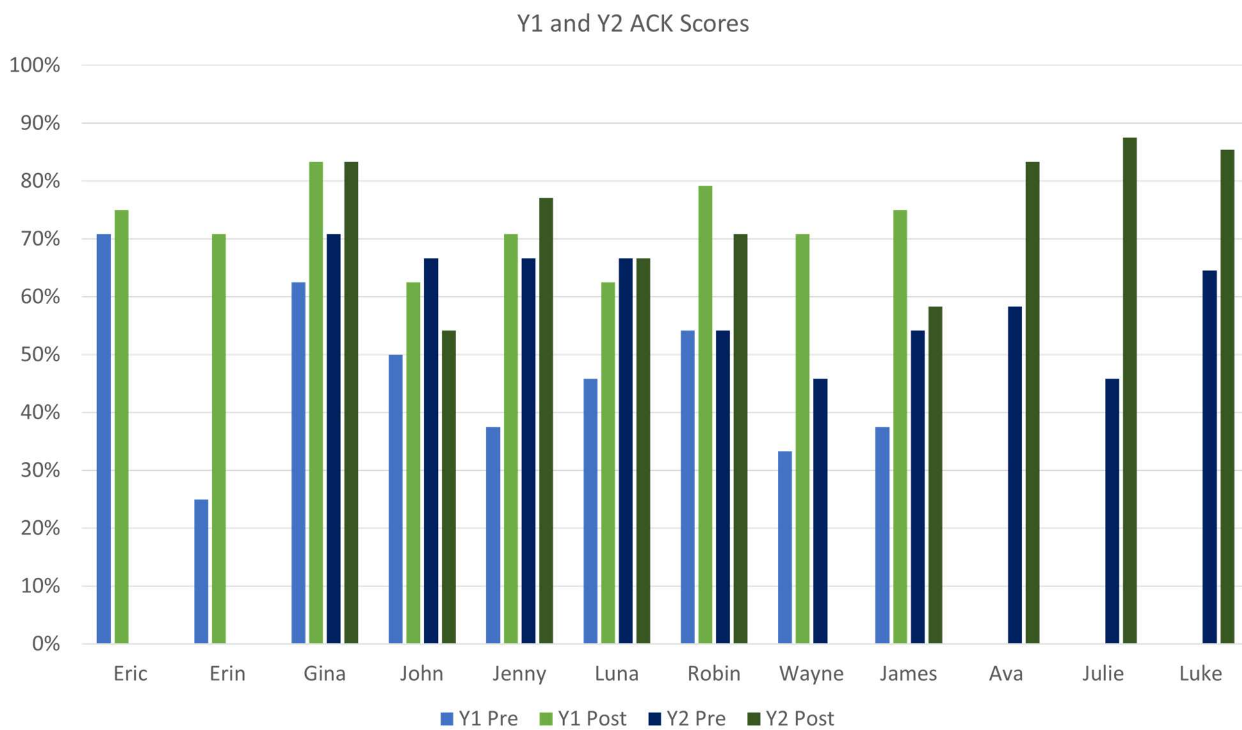
Scores for each individual statement were also evaluated using a paired t-test (see Appendix E). In Y1, four statements showed statistically significant increases: I have the necessary skills to teach this topic (from 4.22 to 4.89, p=0.0497), I understand the content well enough to teach this effectively (from 4.22 to 4.89, p=0.0222), I know how to effectively address learners' misconceptions (from 4.00 to 4.56, p=0.0222), and I am able to use examples to teach this topic (from 4.11 to 5.00, p=0.0207). In Y2, five statements showed statistically significant increases: I feel confident when explaining climate concepts (from 3.90 to 4.40, p=0.0133), although this is a complex topic, I feel prepared to teach it (from 3.80 to 4.50, p=0.0081), I understand the content well enough to teach this effectively (from 3.70 to 4.60, p=0.0028), I know how to effectively address learners' misconceptions (from 3.90 to 4.50, p=0.0222), and I am able to use examples to teach this topic (from 3.90 to 4.70, p=0.0092).

Academic Content Knowledge (ACK)

ACK was measured through a series of free-response questions based on OAS-S standards, graded by several research assistants using a pre-designed rubric (see Figure 2).

Figure 2.

Y1 and Y2 Average ACK Scores for Each Participant.



Paired t-tests on participant's mean ACK scores from pre- to post-test showed a statistically significant increase in Y1 from 46% (SD=14.6%) to 72% (SD=6.9%) with t=5.7, p=0.00045, and SDD=13.6%. Y2 ACK values also showed a statistically significant increase from means of 59% (SD=9.1%) to 74% (SD=12.2%) with t=2.5, p=0.035, and SDD=15.75%. Between Y1's post-test and Y2's pre-test, participants that attended both Y1 and Y2 displayed a slight, non-statistically significant decrease in mean ACK from 72% (SD= 7.8%) to 61% (SD=9.2%) with t=-2.32, p=0.059, and SDD=12.85%.

Scores for individual questions were also analyzed using a paired t-test. During Y1, five of the eight statements and questions all showed statistically significant increases in score: list Earth's major systems ($p=0.005$), what are contributions to changes in global and regional climate ($p=0.023$), where is Earth's available water located ($p=0.022$), what drives the movement of water on Earth ($p=0.050$), and what influences weather and climate on Earth ($p=0.013$). During Y2, only two of these showed statistically significant increases in scores: list Earth's major systems ($p= 0.005$) and where is Earth's available water located ($p=0.022$).

Discussion

This discussion begins with vignettes of several participants, designed to highlight the unique experiences of teachers from varying backgrounds, strengths, and weaknesses. Three participants were chosen by considering participants for whom we had the most data (those who took part in both Y1 and Y2), those with varying but overlapping strengths and weaknesses (those with a stronger pedagogical foundation or academic content foundation), and their overall interactions with the PD materials. It will then transition into more generalizable conclusions about the entire group by discussing themes in SE, ACK, and the relationships between the two for those who participated exclusively in one year and those who took part in both years.

Participant Vignettes

Luna

Luna identifies as a female of Spanish/Hispanic/Latino origin and falls within the 25-29 age range. She obtained a standard certification through a graduate teacher preparation program and is certified to teach middle level science, biology, and physical science. She has been teaching for three to five years, and currently teaches 7th grade science. While her undergraduate educational background was in biomedical science, she is currently working toward her PhD in science education and, as such, has a strong grasp of both educational theory and pedagogical practices. In her current practice, she conveyed that she strives to be student-centered, a stance that was reflected in her interactions over the course of the PD.

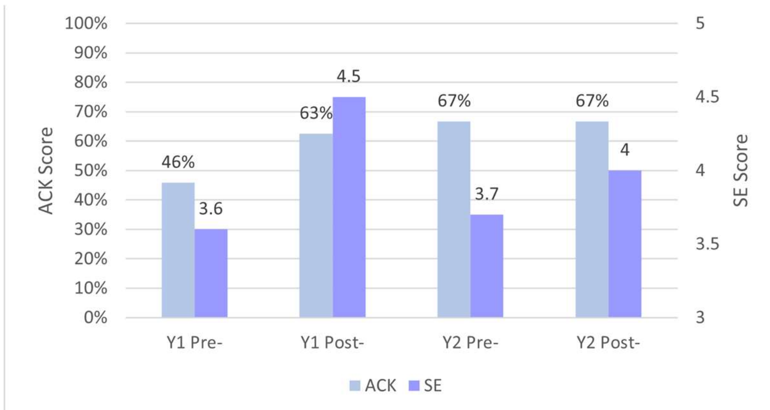
During the PD, Luna often prioritized or sought out “place-based” and community-focused lessons and data sources. She explicitly expressed concern about causing climate anxiety in her students and, as such attempted to inspire hope while conveying information. Her self-study topic over the semester between PDs was “interpretation and creation of data tables, maps, & graphs through Unit 6: Earth Resources & Human Impacts.” Since participating in the PD, she has also sought out support from the Hot Topics group to “revamp” her school’s Natural Resources and Human Impact unit.

Luna’s SE average was initially one of the lower scores but showed a significant increase in between the Y1 pre- and post-tests from 3.6 to 4.5, a 0.9-point increase. This is especially notable in comparison to the average difference in scores in Y1 (0.6) and SDD (0.7) but also exhibited a significant decrease in SE between the Y1 post- and Y2 pre-test from 4.5 to 3.7 (see Figure 3), which is more than doubles the group’s average decrease in SE of 0.4 and the SDD of 0.39; and also equates to a reversion to nearly the pre-PD levels. From the Y2 pre- to post-test, her SE increased from 3.7 to 4, which is slightly less than the average increase of 0.5 in SE score and SDD of 0.44.

As for ACK, Luna’s scores improved from Y1 pre- to post-test from 46% to 63%, which was much less than the average 26% increase, but aligns more thoroughly when considering the 14% SDD. Interestingly, Luna’s ACK average was one of the few to improve slightly between Y1 and Y2, though this pattern did not continue into the Y2 pre- to post-test as her scores remained constant. However, comparing her Y2 scores from pre- to post-test to the average of the differences (13%) and the SDD (16%), the scores are reasonable.

Figure 3.

Luna Average ACK and SE Over Time



John

John identifies as a white/Caucasian male of Spanish/Hispanic/Latino origin in the 50-59 age range. He obtained his standard certification through an undergraduate teacher preparation program as part of his degree in science education and is certified to teach middle level science, biology, physical science, and earth space science. He has been teaching for 16-20 years, and currently teaches high school level Earth Science/Meteorology. While his answers to the question about his level of experience with Earth Science and Science Education courses and PD were inconsistent, it is our understanding that he took several earth science courses at the undergraduate level (three to five or eight or more), took eight or more undergraduate education courses, has participated in approximately five earth science PDs, and attended eight or more science education PDs.

While in the program, he expressed concern about several classroom management issues such as student participation and cellphone use as well as “the recent push to turn students into activists." As a self-proclaimed "skeptic," John possessed several deep-rooted misconceptions about anthropogenic climate change science, and a distrust in scientific data that didn't align with his beliefs. This led to emotional outbursts on several occasions in addition to accusations of facilitators providing biased data and information. For example, John often shifted blame away from the United States to China and India and was visibly distressed and argumentative during discussions of emissions per capita across the globe. On another occasion, during a group activity to decipher data and figures from the IPCC report, John appeared agitated and left the room to express his discontent to an unaffiliated staff member in the college dean's office. However, while he was skeptical about anthropogenic impacts to climate change, he was very vocal about his concerns surrounding pollutants in the ocean in the form of the Great Pacific Garbage Patch.

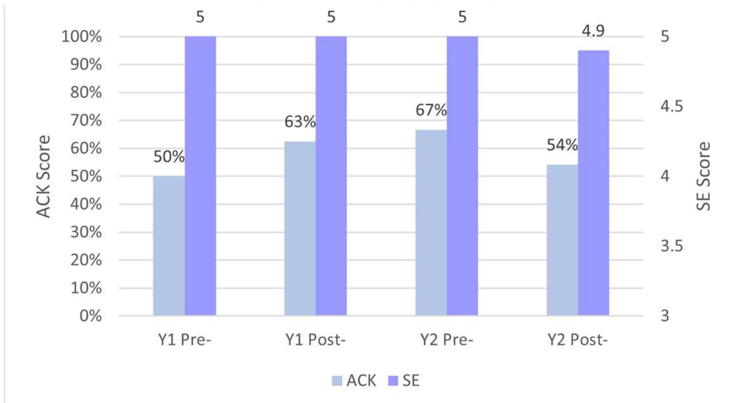
John's SE showed little to no significant change over the course of the PDs (see Figure 4). He maintained the highest levels of SE for all statements until the Y2 post-test, where he marked "I am able to answer learners' questions about climate change" as a four. While his ACK scores showed slight improvements between the Y1 tests, which were well within expectations of the group scores' average difference of 26% with an SDD of 14%, they did not necessarily align with his self-efficacy values. Another interesting point in the data comes from the Y2 pre- to post-test ACK scores—which identify him as the only participant to experience a decrease in ACK after a PD iteration. However, it is worth noting that the post-test occurred on the same day as his foray into the dean's office, which could have impacted his scores as it decreased in only two areas:

- What influences weather and climate on Earth?
- Describe human impacts on Earth's systems.

John, like Luna, also displayed a slight increase in ACK between the Y1 post- and Y2 pre-tests from 63% to 67%.

Figure 4.

John's Average ACK and SE Over Time



Gina

Gina identifies as a white/Caucasian female in the 30-39 age range. She obtained an alternative certification to teach Chemistry and Earth and Space Science and has been teaching for three to five years. Currently, she teaches high school level chemistry/AP chemistry and earth science/meteorology. While Gina has an undergraduate degree was in geology and, thus, extensive background in earth science, she lacks formal training in pedagogy and educational theory. She spoke often about her desire for more pedagogical strategies, reliable information and data sources, and methods for integrating real data into her classes.

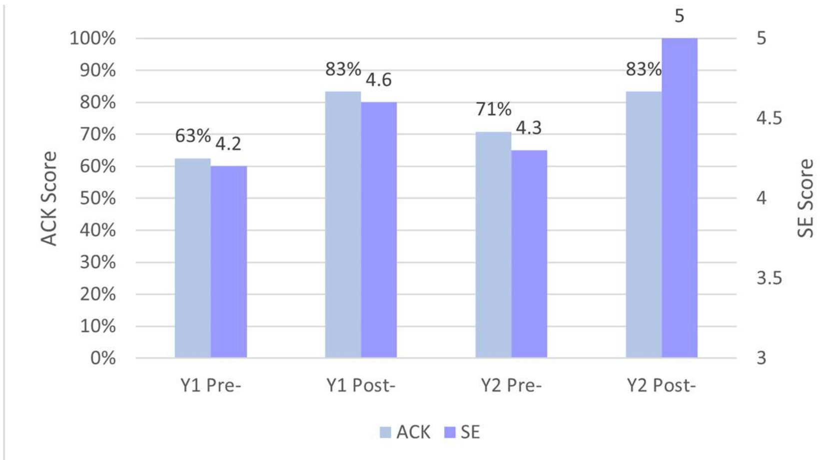
During her time in the PD, Gina was initially rather soft-spoken, often deferring to the other, veteran high school teachers in her group. However, over time, she began to speak up more about implementing specific ideas being modeled and discussed in the group. Her topic for self-study was "implementing Hot Topics ideas and activities in each class," for which she demonstrated evidence of following through with on presentation day during the semester PD sessions. This included a slideshow with a variety of Hot Topics activities and lessons she had adapted and used in each of her different classes, along with reflections on how to improve upon or better adapt each of them to her individual context.

Gina showed a slight increase in SE between the Y1 tests, though it was slightly less than the average increase of 0.6 (SDD=0.7). Between the Y1 post- and Y2 pre-test (see Figure 5), Gina experienced a loss in SE that reduced her average to one similar to her initial value, which aligns with the expectation for a difference in mean SE of 0.4 (SDD=0.4). The Y2 pre- and post-tests but also exhibited a slight increase in SE that aligns with the mean difference of 0.5 (SDD=0.4). Overall, from her initial to final SE scores, Gina displayed an increase in SE that aligns with the expectations obtained from the group data.

Gina's ACK scores improved from the Y1 pre- to post-test and Y2 pre- to post-test, with scores that align with the expected results from the group with a mean difference of 26%, (SDD=14%) and a mean of 13% (SDD=16%) respectively. During the time between the Y1 post-test and the Y2 pre-test, Gina's ACK also decreased from 83% to 71%, aligning with the group's average decrease in score of -11.2% (SDD=12.85%). While Gina's scores are far from perfect, her follow-through on obtaining her goals and implementing strategies into her classroom are an example of working with and excelling through the framework of the PD program.

Figure 5.

Gina average ACK and SE Over Time



Overarching Group Themes

Self-Efficacy

The majority of participants experienced an increase in SE from pre- to post-test. During Y1, six increased, two remained the same, and one decreased. During the time between Y1 and Y2 five of the seven participants decreased while the other two remained the same. Y2 showed an increase in seven, one remained the same, one decreased, and one was absent. Overall, participation in the PD resulted in improved self-efficacy in participants in both years. However, during the time between the semester and the second year of the PD, returning participants showed a statistically significant decrease in SE. Indeed, a majority of returning participants' Y2 pre-scores were reduced to nearly their initial Y1 pre-scores.

This decrease in SE between Y1 and Y2 can be attributed to a variety of factors, however one likely factor, based on their statements during the semestral PD days, was that actually translating and implementing the concepts that they learned and created was often much more difficult than maintaining the status quo in their classrooms. Another potential impact on sustained SE was the reduction in facilitator support during the implementation period of the semester. Check-ins and feedback were spaced out temporally, relied on participants conveying clear and honest perceptions of their own efforts in implementing new strategies to better align with the goals they set, and were poorly attended. Absences and lack of participation likely also contributed to the reduction in the broader sense of community in the group. From this perspective, the PD was successful in short-term increases to SE but is difficult to assess in terms of long-term impacts on SE.

ACK

ACK scores demonstrated significant increases overall from pre- to post-test in Y1 and Y2. There are two exceptions wherein teachers' scores did not increase between pre- and post-tests. Both occurred during Y2, when John's score dropped from 67% to 54% and Luna's remained at 67%. During the time between Y1 and Y2, five of the seven participants' ACK scores decreased while the other two (John and Luna) increased by several points. Y2 showed an increase in seven, one remained the same, one decreased, and one was absent. Overall, participation in the PD resulted in improved academic content knowledge in participants in both years. However, during the time between the semester and the second year of the PD, returning participants' average ACK showed a slight, but insignificant decrease. It is likely that participation in the Hot Topics in Earth Science PD did improve ACK in the short-term, however, it is unclear whether these results persist over time. Further work is needed in order to properly assess long-term ACK retention, especially given the slight decrease observed between Y1 and Y2 in spite of continued semestral meetings. One factor that may influence retention of ACK is the lack of continued use in their classroom setting. The standards discussed in the ACK test were based off of OAS-S standards, however not all of these standards are those used by each grade level or subject, leaving minimal opportunities for teachers to reinforce their own understandings during the semester when their focus is on meeting specific standards; especially if they were not able to implement the Hot Topics methods and techniques that allow them to make use of that ACK in connection to the standards that they must cover in their classrooms.

Comparing SE and ACK

While previous studies have found moderate correlations between SE and academic performance; there is not a standard definition for academic performance, which varies between contexts, nor is there a way to account for potentially influential extraneous factors such as effort regulation, deep processing strategies, and goal orientations (Honicke & Broadbent, 2016). As such, this study does not attempt to draw significant conclusions from the data. Rather, the intent is to simply to present the data in a different manner to show that self-efficacy and academic achievement in the form of ACK do not necessarily align with each other. Such is the case for both Y1 scores (see Figure 6) and Y2 scores (see Figure 7). Broadly speaking, there appears to be a pattern of overconfidence compared to performance among participants.

Figure 6.

Y1 Self-Efficacy Compared to Academic Content Knowledge

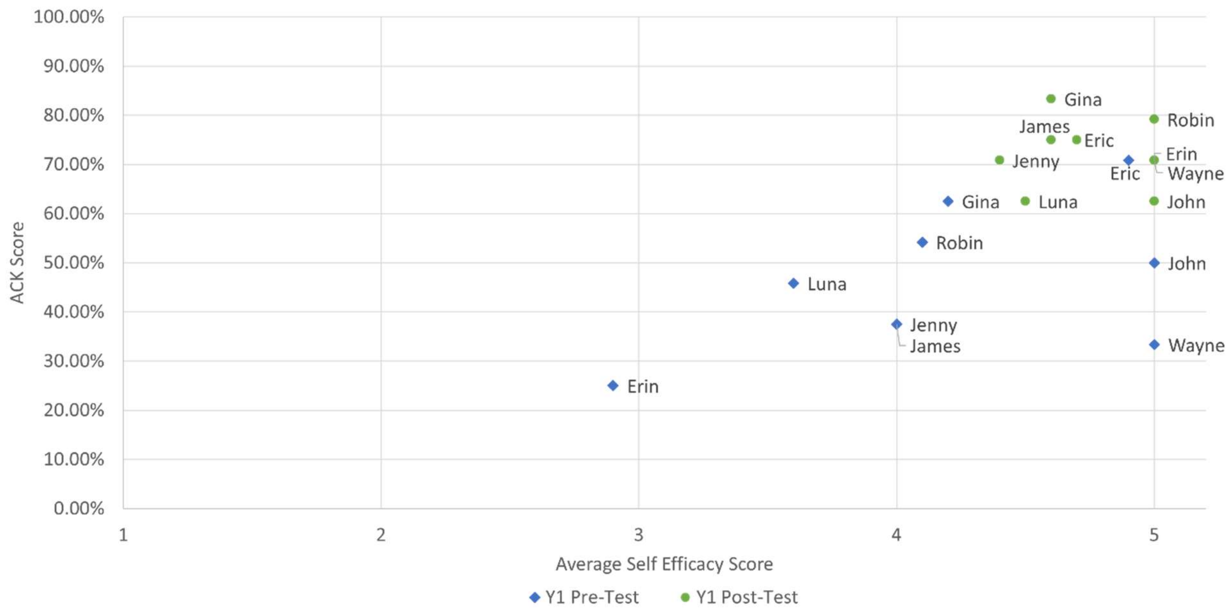
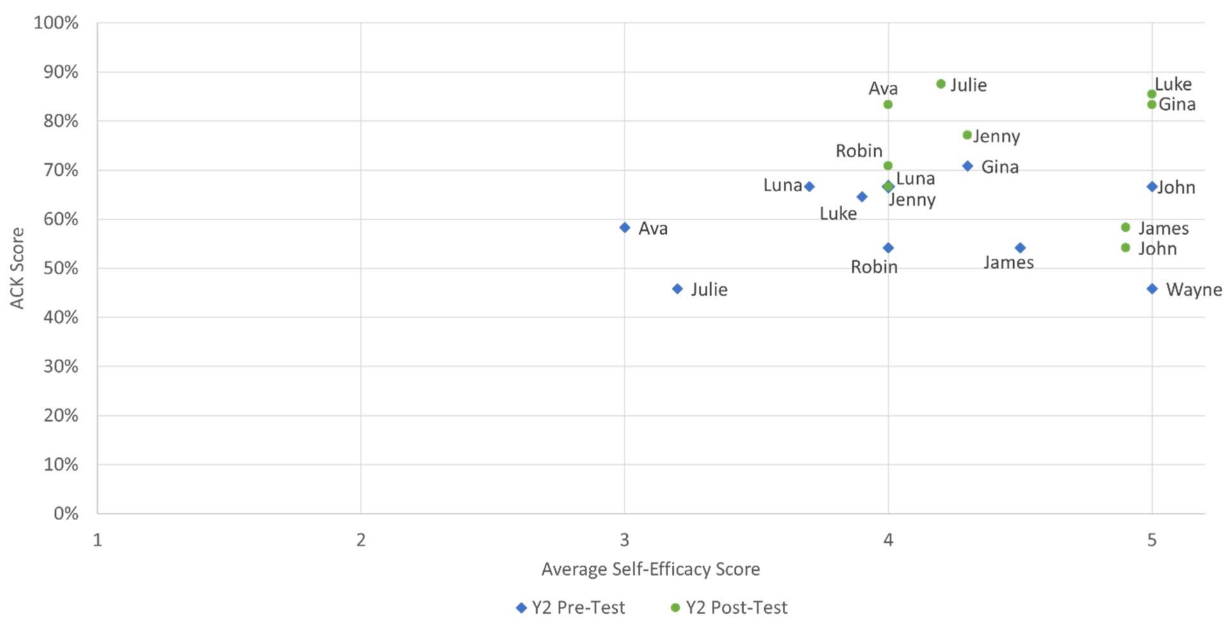


Figure 7.

Y2 Self-Efficacy Compared to Academic Content Knowledge



Conclusions

This study sought to evaluate the effectiveness of the Hot Topics in Earth Science PD, a 2-week PD with two iterations that was designed for in-service secondary science teachers. Several overarching themes can be utilized to summarize the findings. The PD effectively and significantly improved both SE and ACK on a short-term scale from pre- to post-test in both years. More work must be done to delineate longer-term impacts, as statistically significant decreases in SE were observed, along with slight and non-significant drops in ACK between the returning participants' Y1 post-test and Y2 pre-tests. Finally, and on a more individual level, this PD touched upon the idea that deep-rooted misconceptions must be confronted over time and on a more personal level, whether that topic is related to the academic content (ex. climate change denialism) or pedagogical content (ex. the role of the teacher, assessment strategies). Those who were more open to making changes and receiving feedback were more likely to follow through on the implementation of those practices.

Future Work

Additional qualitative analysis will be undertaken using NVivo 15 to characterize participant products, such as models of Earth's systems and interactions and lesson plans for evidence of ACK and PCK respectively. Future work should consider addressing the potential for long-term SE and ACK loss by implementing additional, consistent evaluations and the potential for more interventions over time. Additional understanding of the impacts of the PD on implementation could be done by implementing classroom observations before and after intervention, rather than relying on personal accounts and sample lesson plans from participants.

Chapter 4. Summary, Overarching Themes, and Future Work

The purpose of this thesis was to document the development of a global climate change-related professional development (PD) program designed for secondary science teachers from the literature review and planning stage through the final evaluation phase. The following chapter seeks to summarize what has been done, what the results were, and where to go from here.

Summary

The original goals of this PD were threefold. The first was to design and implement a PD that improves teacher's understanding and self-efficacy (SE) with regard to climate change science or ACK and teaching the content or PCK. A second goal was to curate resources that are contextually applicable to each participant, such as standards-oriented classroom activities and lessons, data sources, funding and grant opportunities, and local organizations and contacts. The third and final goal was to build community between local teachers in similar subject areas across the secondary levels.

PD from Ideas to Evaluation

Developing a PD about a topic with vast scientific, social, and political connotations requires thorough literature review that goes far beyond the science. Facilitators sought to understand more about topics such as anticipating and combatting mis- and disinformation, teaching potentially emotionally- or politically-charged topics, and climate change-specific PD and pedagogies in addition to the more fundamental frameworks of teaching and developing PD. During the design phase, facilitators emphasized the importance of exploring context-specific content, from an academic and pedagogical perspective. Analyzing, understanding, and drawing connections between the Oklahoma science standards (OAS-S) was integral before lesson outlining began. Participant recruitment took place after initial outlining the broad topics and during the gathering, development, and adjusting individual lesson plans. Despite having developed outlines and lesson plans, the facilitators were prepared to adjust and adapt from the first day in order to better accommodate the participants' goals and desires. Both iterations of the PD, as well as the semestral sessions were accomplished with few surprises.

Results of the PD

In the short term, both iterations of the PD were successful in influencing statistically significant increases in SE and ACK from pre- to post-test. However, returning participants did experience a statistically significant loss in SE ($p=0.047$) from Y1's post-test to Y2's pre-test. Similar, though not statistically significant drops in ACK were also observed. As such, while the PD did improve both SE and ACK in the short-term, it remains to be seen whether there is a lasting effect of taking part in the PD. Additionally, individuals tended to have slightly exaggerated SE in comparison to their ACK performance, which—in the case of a topic as complex as earth's systems in the context of climate change—may be slightly attributed to a case of "not knowing what you don't know." Finally, at a more individual level, this professional development underscored the necessity of systematically addressing deeply entrenched misconceptions over time, whether they pertain to academic content—such as climate change denial—or pedagogical approaches, including the role of the teacher or assessment strategies. Individuals who demonstrated a greater openness to change were typically more inclined to implement those modifications to their practices effectively and consistently.

Suggestions for Future Work

Global climate change will continue to be a reality. Understanding the broad scale science and societal implications can assist in creating a better-informed public. By educating teachers through the use of PD, there is a greater chance for that information to spread to large groups of young people through formal education. As such, the creation and implementation of impactful, effective climate change-related PD will only grow in its importance.

With respect to the data collected in this study, future work will include qualitative coding analysis of participant products for further insights into the development of PCK and ACK. This includes participants' lesson plans, reflective responses, and earth system models (examples of which can be seen in Appendix F). Any additional implementations of this PD framework would likely benefit from utilizing classroom visits and interviews of students to evaluate participants' pre- and post-intervention teaching methods could allow for a much richer dataset, rather than relying on participants' lesson plans. Finally, attention should be given to exploring the long-term impacts of this type of PD on SE and ACK; and potential strategies to mitigate potential losses by incorporating ongoing, systematic evaluations and considering the implementation of additional interventions over time.

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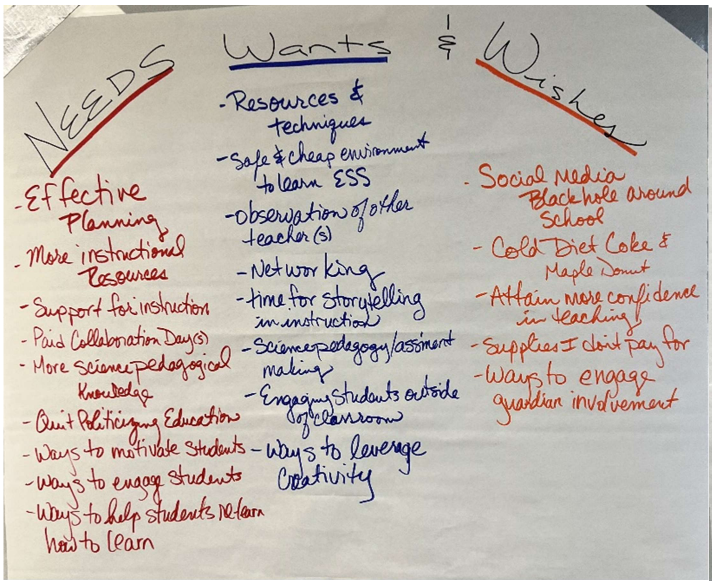
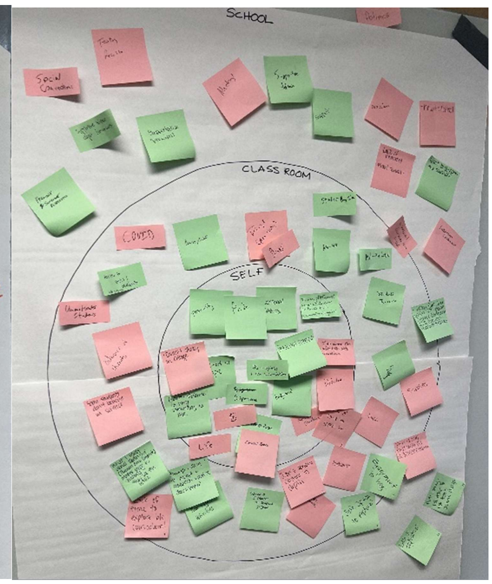
Appendix

A. Participant Products and Activities

Y1

Day 1: Needs, Wants, and Wishes List (top left); Success & Challenges of Earth Science Teaching (top right); and Rapid Fire Earth Science Planning (bottom)





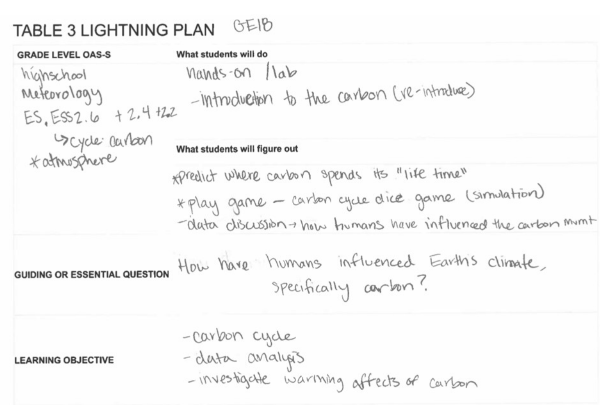
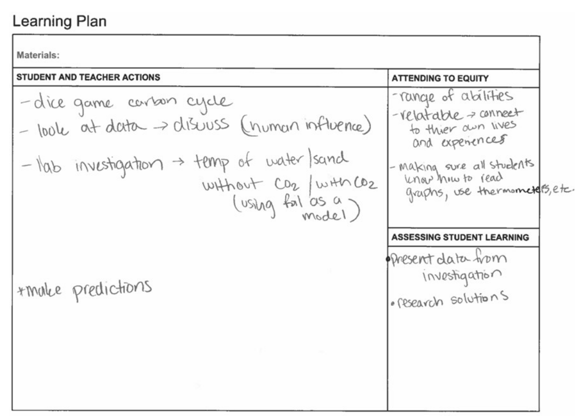


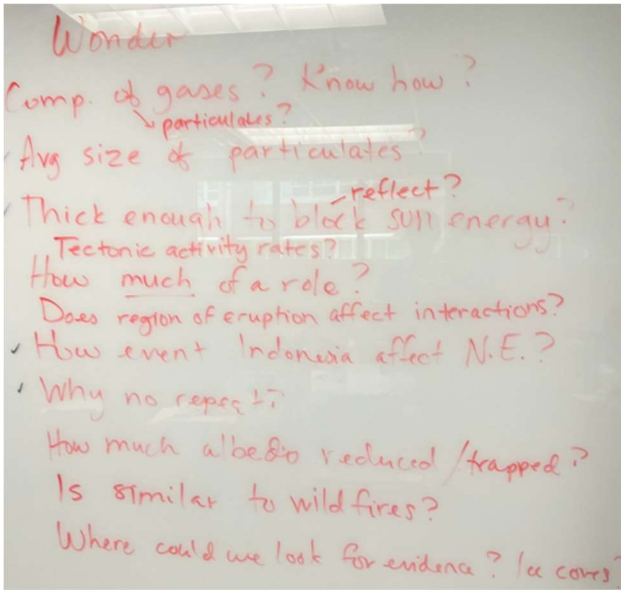
TABLE 3 LIGHTNING PLAN GEIB

GRADE LEVEL OAS-S	What students will do
highschool Meteorology ES.ESS2.6 + 2.4 + 2.2 ↳ cycle: carbon + atmosphere	hands-on /lab -Introduction to the carbon (re-introduce)
	What students will figure out
	*predict where carbon spends its "life time" *play game – carbon cycle dice game (simulation) -data discussion → how humans have influenced the carbon amount
GUIDING OR ESSENTIAL QUESTION	How have humans influenced Earth's climate, specifically carbon?
LEARNING OBJECTIVE	-carbon cycle -data analysis -investigate warming affects of carbon


Learning Plan

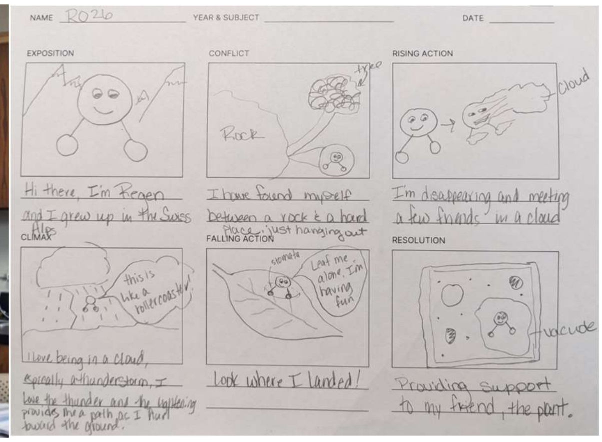
Materials:	
STUDENT AND TEACHER ACTIONS	ATTENDING TO EQUITY
-dice game carbon cycle -look at data → discuss (human influence) -lab investigation → temp of water/sand without CO_2 / with CO_2 (using foil as a model) *make predictions	-range of abilities -relatable → connect to their own lives and experiences -making sure all students know how to read graphs, use thermometers, etc.
	ASSESSING STUDENT LEARNING
	•present data from investigation •research solutions

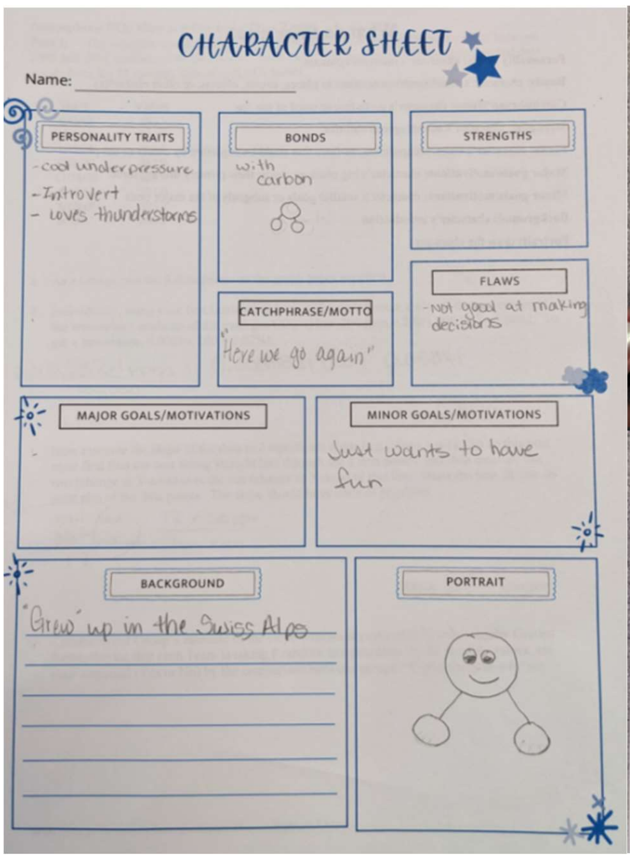
Day 2: The Year Without Summer Participant Wonder List (left) and Table 2's Initial Systems Models with Gallery Walk Comments (right)

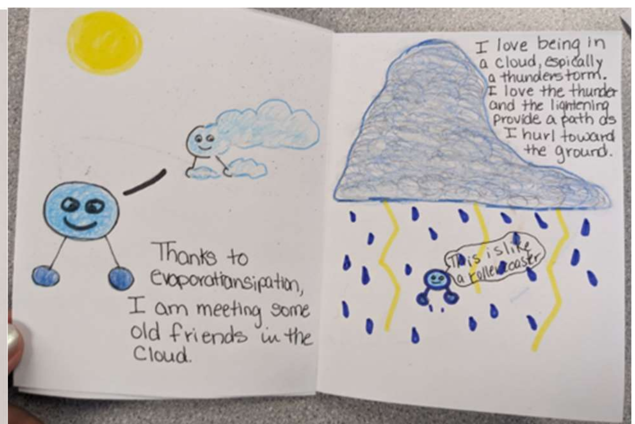


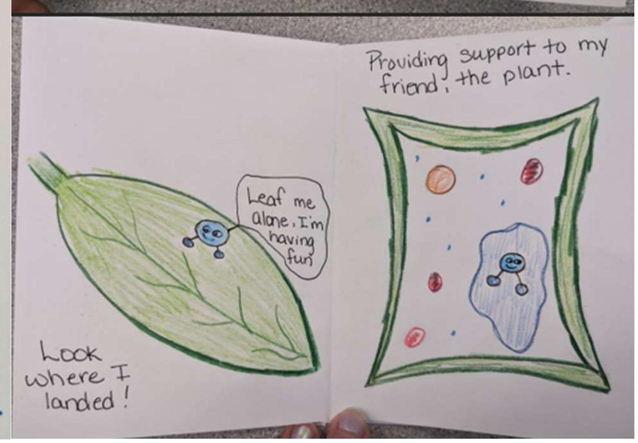
Day 3: Modeling Earth's Water Content-Globe Game (left) and Water Reservoirs Model (right)

Day 4: Modeling the water cycle (top left) and Robin's water cycle zine materials





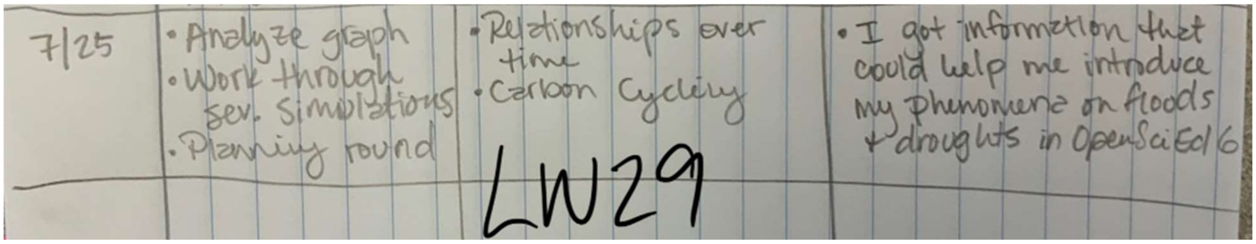


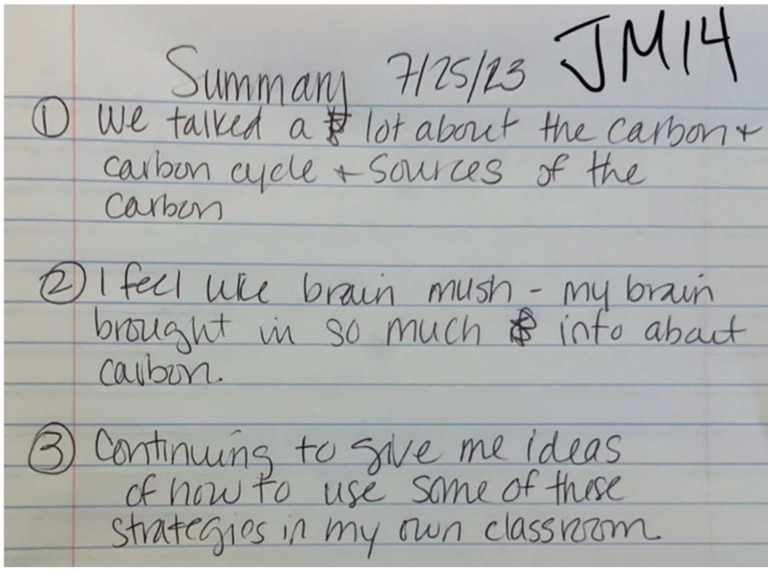


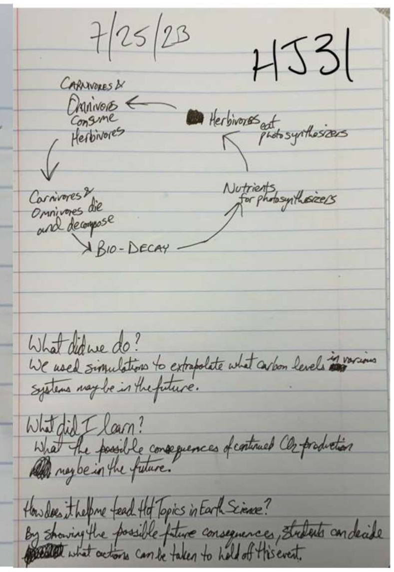
Day 5: Weather and climate simulations and models (left) and revising models (right)

Day 6: Exploring albedo, taking the data

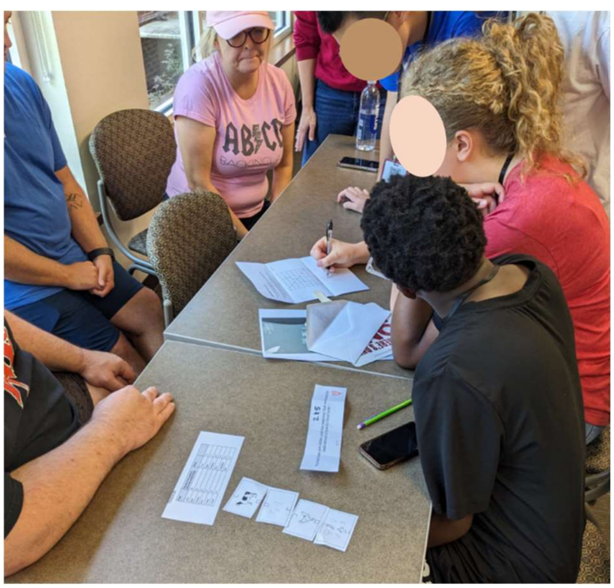
Day 7: Participant reflections of the day—Luna (top), Jenny (bottom left), and John (bottom right)

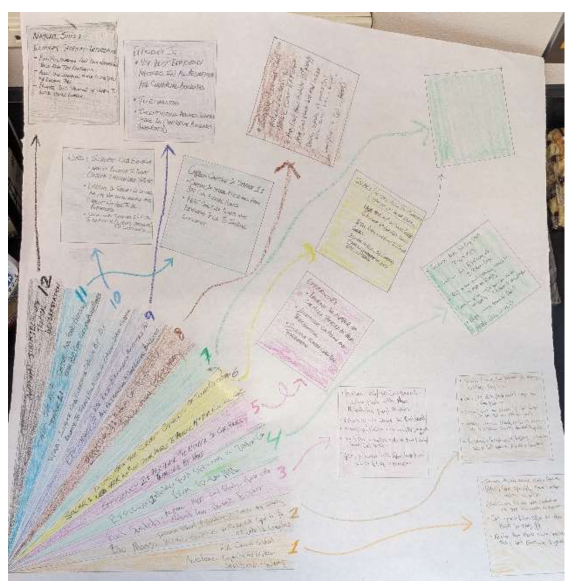

7/25
• Analyze graph
• Work through sev. simulations
• Planning round
• Relationships over time
• Carbon Cycling
• I got information that could help me introduce my phenomena on floods + droughts in OpenSciEd 6
LW29


Summary 7/25/23 JM14
① We talked a lot about the carbon + carbon cycle + sources of the carbon
② I feel like brain mush - my brain brought in so much info about carbon.
③ Continuing to give me ideas of how to use some of these strategies in my own classroom


7/25/23 HJ31
Carnivores & Omnivores Consume Herbivores
Herbivores eat photosynthesizers
Carnivores & Omnivores die and decompose
Bio-Decay
Nutrients for photosynthesizers
What did we do?
We used simulations to extrapolate what carbon levels in various systems may be in the future.
What did I learn?
What the possible consequences of continued CO_2 production may be in the future.
How does it help me teach Hot Topics in Earth Science?
By showing the possible future consequences, students can decide what actions can be taken to hold off this event.

Day 8 and 9: Practicing scaffolding with local children during a carbon cycle breakout box challenge (left) and Table 4's modified Wedges Game (right)





B. Demographic Data

Alias	Pseudo-nym	Gender	Age Range	Race; Ethnicity	Undergraduate Background	Certification Status	Courses Certified to Teach	Years Teach-ing	Grades or Classes Taught
EH90	Eric	Male	40-49	White or Caucasian, Black or African American	Psychology and Biological Sciences	Alternative	Middle Level Science, Physical Science	21+	8th Grade, Physical Science
EN37	Erin	Female	30-39	White or Caucasian	Multidisciplinary Studies	Alternative	Elementary	3-5	Elementary
GE18	Gina	Female	30-39	White or Caucasian	Geology	Alternative	Chemistry, Earth and Space Science	3-5	Chemistry/ AP Chemistry, Earth Science/ Meterology
HJ31	John	Male	50-59	White or Caucasian; Hispanic/ Latino/ Spanish origin	Science Education	Standard, Undergraduate Program	Middle Level Science, Biology, Physical Science, Earth and Space Science	16-20	Earth Science/ Meterology
JM14	Jenny	Female	30-39	White or Caucasian	Biology	Alternative	Biology	6-10	7th Grade
LW29	Luna	Female	25-29	Other; Hispanic/ Latino/ Spanish origin	Biomedical Science	Standard, Graduate Program	Middle Level Science, Physical Science, Biology	3-5	7th Grade

RO26	Robin	Female	50-59	White or Caucasian	Elementary Education	Standard, Undergraduate Program	Middle Level Science, Middle Level Other, Elementary	21+	8th Grade
WJ03	Wayne	Male	40-49	White or Caucasian, American Indian/ Native American or Alaska Native	Science Education	Standard, Undergraduate Program	Middle Level Science, Biology, Chemistry, Earth and Space Science	21+	Earth Science/ Meterology
WJ24	James	Male	Under 25	White or Caucasian	Elementary Education	Standard, Undergraduate Program	Elementary	0-2	6th Grade
AW74	Ava	Female	40-49	White or Caucasian	Nursing	Alternative		0-2	6th Grade, 7th Grade, 8th Grade
JM20	Julie	Female	40-49	White or Caucasian	Health, Physical Education and Recreation	Standard, Undergraduate Program	Middle Level Science, Middle Level Other, Physical Science, Earth and Space Science, PE, Health & Safety	21+	7th Grade
LD17	Luke	Male	25-29	White or Caucasian	Physics	Standard, Graduate Program	Chemistry, Physics, Physical Science	0-2	Physical Science

C. The CCTEBI, used for Self-Efficacy Analysis

Likert scales from strongly disagree (1) to strongly agree (5)

1. I am able to answer learners' questions about climate change.
2. I welcome learners' questions on this topic.
3. I feel confident about answering learners' questions.
4. I have the necessary skills to teach this topic.
5. I feel confident when explaining climate concepts.
6. Although this is a complex topic, I feel prepared to teach it.
7. I understand the content well enough to teach this effectively.
8. I am able to anticipate learners' common misconceptions related to climate science.
9. I know how to effectively address learners' misconceptions.
10. I am able to use examples to teach this topic.

D. ACK Rubrics

Question 1. List Earth's major systems.

Score (0-3)	Name	With Cryosphere	Without Cryosphere*
Missing (0)	Missing/ unanswered/ "I don't know"	**Hydrosphere**	**Hydrosphere**
Attempted (1)	Systems are mostly (3+) absent or incorrect	**Cryosphere**	**Geosphere**
Some Errors (2)	Systems are listed but may have a couple (1-2) missing or incorrect	**Geosphere**	**Biosphere**
Excellent (3)	All systems are named correctly	**Biosphere**	**Atmosphere**
		Atmosphere	

*note: if they do not list/define the cryosphere but mention ice/solid water within their description of the hydrosphere, that still counts

Question 2. Describe Earth's major systems.

Score (0-3)	Description	With Cryosphere	Without Cryosphere
Missing (0)	Descriptions are absent or factually incorrect	**Hydrosphere**: comprising all water present on Earth (i.e. oceans, groundwater, surface water) **Cryosphere:** all frozen/solid water (ice) on Earth (i.e. snow, glaciers, ice caps)	**Hydrosphere**: comprising all solid/liquid water present on Earth (i.e. oceans, groundwater, surface water, **ice/snow**)
Attempted (1)	Systems are mostly (3+) absent or incorrect	**Geosphere:** includes the solid Earth (core, mantle, crust, soil, rocks)	**Geosphere:** includes the solid Earth (core, mantle, crust, soil, rocks)
Some Errors (2)	Descriptions are mostly present (1-2 may be missing or incorrect)	**Biosphere:** consists of all living organisms on Earth (i.e. plants, animals, fungi) and organic matter that has yet to decompose	**Biosphere:** consists of all living organisms on Earth (i.e. plants, animals, fungi) and organic matter that has yet to decompose
Excellent (3)	All systems are named correctly	**Atmosphere:** comprises the thin layer of gases and suspended particles that surround the Earth (predominantly N_2, O_2, Ar, CO_2, and H_2O)	**Atmosphere:** comprises the thin layer of gases and suspended particles that surround the Earth (predominantly N_2, O_2, Ar, CO_2, and H_2O)

*note: if they do not list/define the cryosphere but mention ice/solid water within their description of the hydrosphere, that still counts

Question 3. How do Earth's major systems interact to affect Earth's surface materials and processes?

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/"I don't know"
Attempted (1)	May list interactions and impacts that are not scientifically accurate. May include examples of how 1 system provides a space for surface materials and processes (i.e. the biosphere holds all life on Earth) but does not describe interactions between spheres and the resulting impacts on Earth's surface processes and materials.
Some Errors (2)	Mentions several spheres' interactions with each other and their impacts on Earth's surface materials/processes but may miss 1 or 2.
Excellent (3)	Describes surface materials and processes that are directly impacted by Earth's systems and explain how (note that they do not have to explicitly name each sphere but should state a component i.e. water for hydrosphere, oxygen for atmosphere, soil for geosphere, etc.).

Question 4. What are contributions to changes in global and regional climate?

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/"I don't know"
Attempted (1)	Does not fully answer the question or answers contain misconceptions
Some Errors (2)	Answers are factually correct but may be incomplete or lack depth. This could include mentioning only influences on either global or regional climate.
Excellent (3)	Mentions multiple, factually correct examples of contributions to global and regional climate. Must give an example for both global and regional. Ex. land use changes, changes in snow/ice/glacier distribution and amount (albedo), variation in orbital parameters (changes in celestial movement), tectonic outgassing, etc.

Question 5. Where is Earth's available water located?

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/"I don't know"
Attempted (1)	May have listed a couple of reservoirs, including unavailable ones
Some Errors (2)	Only listed either groundwater or surface water. May have mentioned the ocean as "available," though it is not usable. -Mentions either multiple forms of groundwater or surface water
Excellent (3)	Most of Earth's water is in the ocean but is not useable in spite of being available Of the freshwater: -Groundwater is the largest useable reservoir -Surface water is usable in some cases (i.e. rainwater, rivers, lakes) -Other reservoirs include saline lakes, soil moisture, swamps/marshes, glaciers/ice caps, ice/snow, which may be unusable or difficult to access -Mentions reservoirs of both groundwater and surface water

Question 6. What drives the movement of water on Earth?

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/"I don't know"
Attempted (1)	Put an answer that has to do with water (i.e. precipitation)
Some Errors (2)	Valid but incomplete or vague response
Excellent (3)	Forces: solar radiation and gravity

Question 7. What influences weather and climate on Earth?

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/“I don’t know”
Attempted (1)	May mention processes that are factually incorrect or misguided
Some Errors (2)	Information provided is factually correct but may be vague. May only mention factors that specifically influence weather OR climate but not both. May conflate weather with climate
Excellent (3)	Gives multiple examples of processes that influence weather and climate. Must mention processes that impact both weather and climate, though these may not be the exact same processes

Question 8. Describe human impacts on Earth’s systems.

Score (0-3)	Criteria
Missing (0)	Missing/unanswered/“I don’t know”
Attempted (1)	Denies human impacts on Earth's systems OR acknowledges human impacts but does not elaborate or give an example
Some Errors (2)	Answers are limited and may not draw connections between human action and impacts
Excellent (3)	States how humans impact the systems and mention the connections between systems (feedbacks)

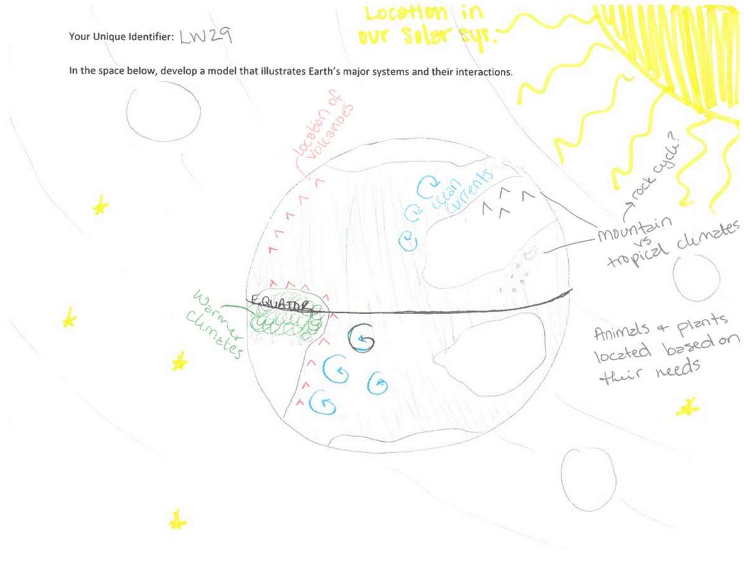
E. SE Statistical Analysis

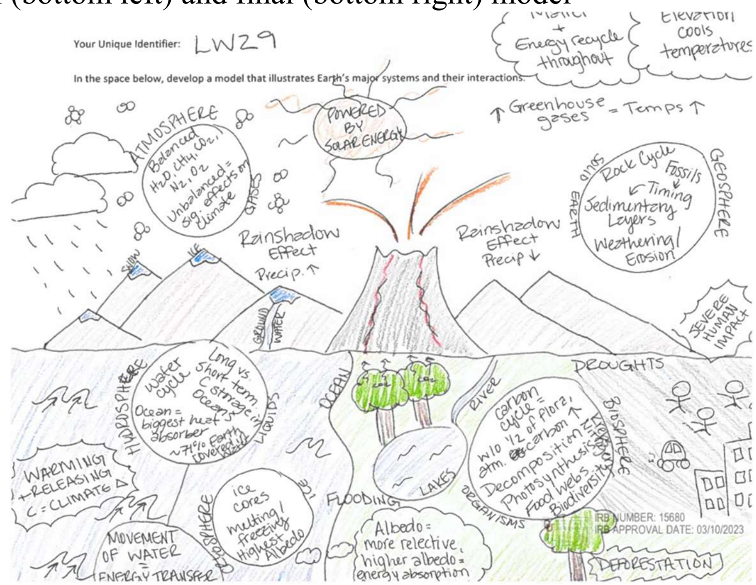
Mean SE scores by statement, highlighted areas indicating statistically significant increases and include p-values below

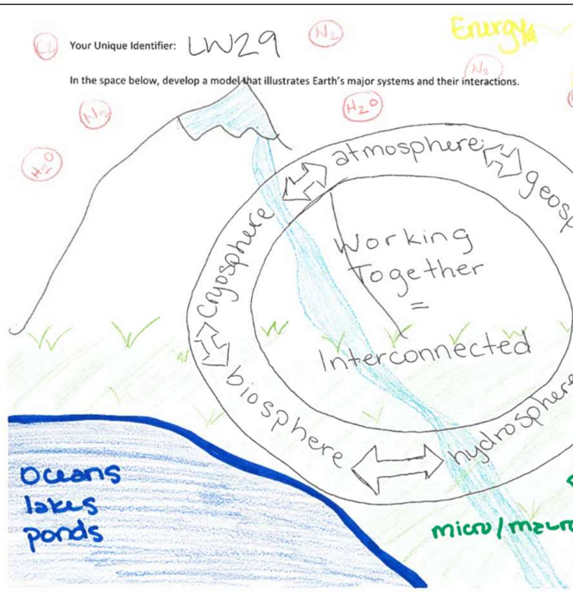
	Year 1 Average Score		Year 2 Average Score	
SE Statement	*Pre-*	*Post-*	*Pre-*	*Post-*
I am able to answer learners' questions about climate change.	4.11	4.56	4.10	4.30
I welcome learners' questions on this topic.	4.67	5.00	4.70	4.80
I feel confident about answering learners' questions.	4.33	4.44	4.20	4.50
I have the necessary skills to teach this topic.	4.22 p=0.0497	4.89	4.30	4.60
I feel confident when explaining climate concepts.	4.00	4.67	3.90 p=0.0133	4.40
Although this is a complex topic, I feel prepared to teach it.	4.11	4.89	3.80 p=0.0081	4.50
I understand the content well enough to teach this effectively.	4.22 p=0.0222	4.89	3.70 p=0.0028	4.60
I am able to anticipate learners' common misconceptions related to climate science.	4.11	4.67	4.10	4.40
I know how to effectively address learners' misconceptions.	4.00 p=0.0222	4.56	3.90 p=0.0222	4.50
I am able to use examples to teach this topic.	4.11 p=0.0207	5.00	3.90 p=0.0092	4.70

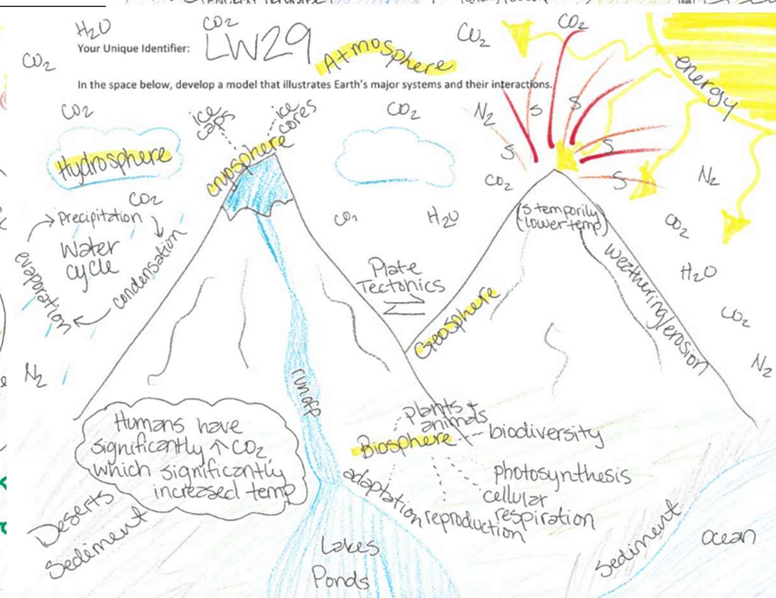
F. Participant's Individual Models from Y1 and Y2

Luna Y1 initial (top left) and final (top right) models and Y2 initial (bottom left) and final (bottom right) model

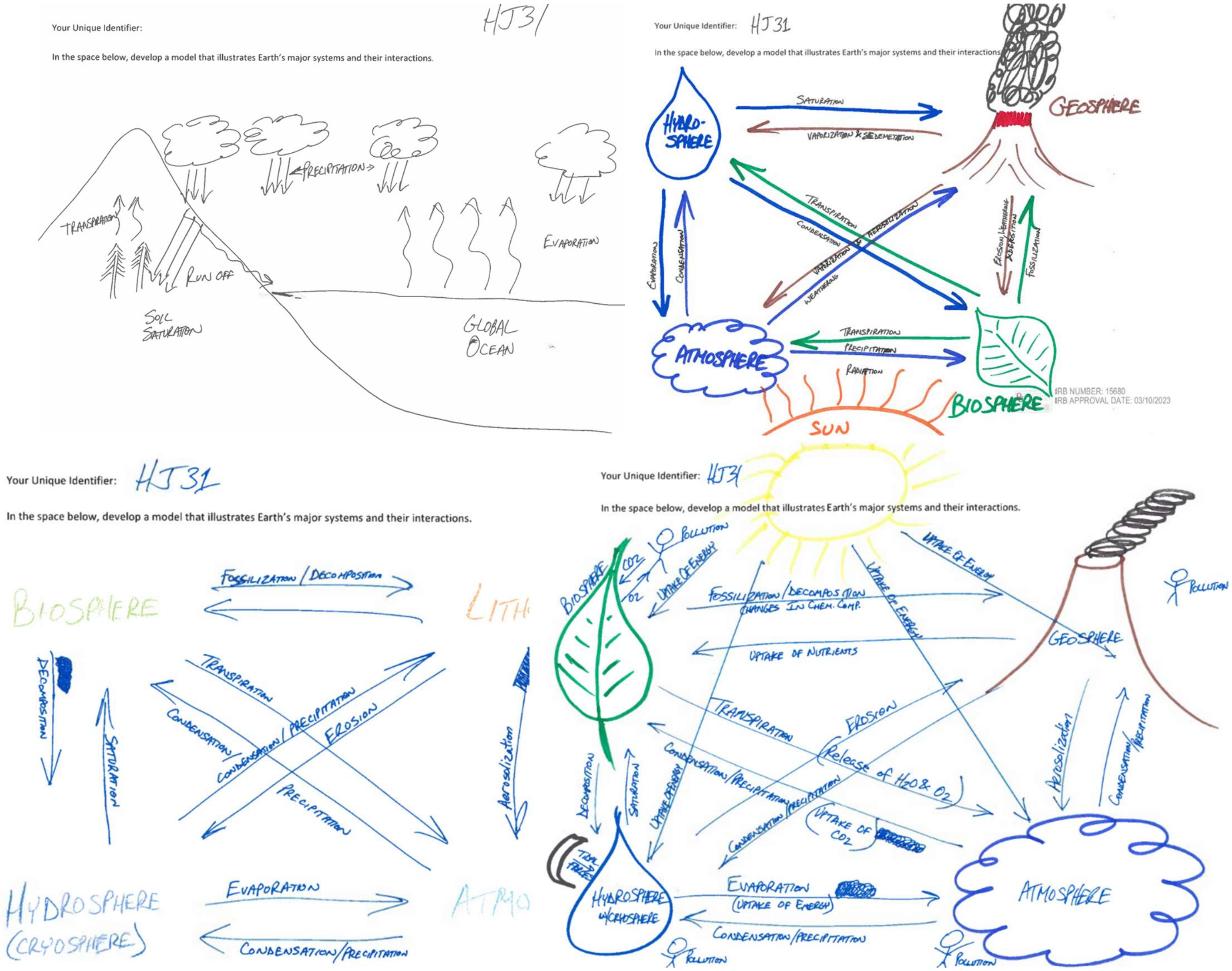








John Y1 initial (top left) and final (top right) models and Y2 initial (bottom left) and final (bottom right) model



Gina Y1 initial (top left) and final (top right) models and Y2 initial (bottom left) and final (bottom right) model