Lessons Learned: Using Socioscientific Issues and Social Justice to Unsettle Environmental Science

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Abstract: This study explores the first year experiences of middle and high school science and math educators who participated in a two-year professional development (PD) focused on designing and implementing instruction based on the frameworks of socioscientific issues (SSI) and socio-transformative constructivism (sTc), an approach to justice-oriented science teaching. The goal was to support teachers in reframing the purpose of learning math and science away from traditional content to encourage students to view math and science knowledge and skills as a tool to promote change in their personal lives, schools, and communities. Teachers were able to choose their own topic for designing instruction, and this qualitative study focused on eight of the 14 teachers participating in the PD who developed and implemented an instructional unit focused on environmental studies. Two research questions guided this study: (a) How did teachers unsettle environmental studies by designing and implementing instruction using the SSI/sTc framework? (b) To what extent did teachers' reflections on their teaching indicate an unsettling of teaching environmental studies? The units designed by teachers focused on environmental SSI topics such as climate change, the use of plastic water bottles, access to clean water, flooding, fast fashion and water resources, and electricity generation and distribution. Findings indicate teachers designed units focused on resolving local, timely issues of environmental injustice, engaged students in reflecting on personal lifestyle choices, and engaged students in taking action. However, there was a discrepancy in teachers' planned units and their reflections, indicating that this unsettling of teaching environmental studies unsettled teachers' pedagogical proclivities. Specifically, 1) teachers considered the social and scientific aspects of the framework as distinctive rather than integrated across lessons; and 2) despite designing units including SSI/sTc, teachers maintained traditional science teaching mindsets and instructional goals that were evident in their enactment and reflections on their teaching. Findings indicate SSI/sTc provides a viable framework to "unsettle" environmental science, but teachers require more support. These findings can inform teacher educators to provide real-world SSI and social justice (SJ) PD workshops to pre-service and in-service educators.

Keywords: *social justice, socioscientific issues, environmental science, teacher professional development.*

Background

Pedagogical decisions often involve numerous value judgments, largely about the best way for students to learn, the intended outcomes of the educational experience, and, for environmental studies, how learners best engage with the environment and/or environmental advocacy (Herman et al. 3). Approaches to environmental education vary greatly, ranging from an emphasis on scientific knowledge and processes toward a more environmental advocacy approach, often foregrounding social justice considerations of issues that unequally affect particular places or peoples (Wang et al. 2). On the other hand, environmental education may vary in the degree to which issues are presented as abstract, decontextualized scientific processes as opposed to promoting a more personal connection for students (Herman et al. 3). Prior research does indicate that teaching with place-based, problem-based, and topics related to environmental justice elevates students' environmental advocacy, particularly related to local issues, and interest in environmental careers, in addition to enhanced student performance on traditional measures of science achievement, particularly at the secondary level (Buxton 13 and Morales-Doyle 15).

In this study, we explore how teachers utilized environmental justice issues as a basis for designing environmental education units for middle and high school students in science classes. We build upon prior work by Herman and colleagues contending that socioscientific issues (SSI) present a useful perspective for both engaging students in learning about environmental science topics and as well as developing the scientific mindsets and skills necessary for students to engage in environmental stewardship (14). SSIs are topics with a basis in science and present debatable and ill-defined problems that have a multitude of views in society and often involve contested science making them important to human society. We utilize the framework of sociotransformative constructivism (sTc) to explicitly attend to social justice, specifically power inequalities related to

the environmental issues. This framework combines elements of social constructivism in science education with multiculturalism (Rodriguez 589). Despite the natural connections between environmental justice and environmental education, little research exists that considers an SSI approach to environmental education with an explicit focus on social justice.

Therefore, the present study was designed to explore teachers' experiences designing, implementing, and reflecting upon units they designed around environmental justice issues. Specifically, we sought to answer the following research questions: (a) How did teachers unsettle environmental studies by designing and implementing instruction using the SSI/sTc framework? (b) To what extent did teachers' reflections on their teaching indicate an unsettling of teaching environmental studies?

Literature Review

In the sections that follow, we contextualize the present study within the literature addressing SSI and sociotransformative constructivism (sTc) and make the case for the application of these pedagogical strategies to environmental education.

SSI

SSI develops students' reasoning skills, including the ability to engage in social complexity, consider multiple perspectives, and exhibit healthy skepticism when presented with new information (McNeill and Vaughn 347). Teaching with SSI is an effective way to address the moral and ethical implications of real-world issues, such as environmental issues, and to enhance science learning and scientific literacy (Zeidler 697). The SSI framework has three distinct yet overlapping domains that drive student learning: social, scientific, and discursive (Minken et al. 130).

The **social domain** focuses on the societal aspects of an issue such as the relevance and interests of the students and the various systems and perspectives of the issue. The social domain includes the elements of *exploration of the SSI*, *consider issue system dynamics*, *and compare and contrast multiple perspectives*. For the element, *exploration of SSI*, teachers needed to choose an SSI with a local and global focus. It must be connected to a math or science topic, consider students' interests, and be relevant to the lives of the students and the curriculum (Zeidler and Kahn 31).

The **scientific domain** is an exploration of the scientific phenomenon or concepts in mathematics associated with the SSI and which is part of the existing curriculum. It includes the elements of *explore and explain the underlying scientific phenomena and/or concepts in mathematics* and *STEM modeling* and provides opportunities for students to actively engage with the science or math content. STEM modeling is an avenue in which students can develop, use, evaluate, and revise models connected to the SSI.

The **discursive domain** is used to encourage students to think logically and analytically. The two elements within this domain, *employ reflective skepticism* and *elucidate one's own position/solution*, encourage students to analyze, critique, or be skeptical of any information connected to their SSI, as well as, use data to explain their position, the strengths and weaknesses of their claims or identify their biases or limitations as connected to the SSI. Students also reflect upon their role in influencing themselves and/or others with regard to the SSI. This domain is the area where teachers struggled the most to incorporate these elements into their units and as such, which offers teachers the most growth.

Framing instruction in this way, and intentional integrating these domains provides a counterpoint to traditional science education. Traditional science teaching methods lack social and

cultural context and emphasize science as a body of knowledge, whereas new paradigms of education place science in a larger social, cultural and political context (Wang et al. 2). The integration of SSI into environmental education cultivates a more meaningful, critical understanding in students that can address the insufficiencies of traditional teaching strategies and guides students to address complex environmental challenges in a complete way. Learning through SSI can facilitate the development of these skills in students and others, including functional scientific literacy and the capacity to analyze a variety of sources of information and perspectives on intricate issues (Ziedler 697). SSI teaching provides students with the opportunity to develop the scientific understanding and evidence-based decision-making skills necessary to develop environmental literacy to involve themselves in the public debate surrounding SSI (Carson 30).

If teachers are to be responsible for helping students with the development of these skills, it is imperative that they possess sufficient forms of reasoning and perspective taking as part of an arsenal of requisite abilities for the implementation of SSI (Owens 2). Past studies demonstrated that persons lacking sufficient reasoning abilities encountered difficulties processing information from multiple perspectives, “which in turn discourages them from endorsing the relative correctness of different views to acknowledge the tentative and complex nature of knowledge” (Zeidler 712). A related conclusion was reached by Lombardi et al. when it was found that enhanced argumentation skills can facilitate conceptual changes and lead to a better understanding of science, promoting argumentation has become an essential element of SSI including climate change education (4). Similarly, as stated by Lui et al., “Individuals need to have a sophisticated understanding of the nature of scientific knowledge—an important component of personal epistemology—to conceptualize the inherent complexity of SSI" (5). The instruction of this fundamental understanding is done through professional development (PD) workshops for

educators. After a three-year PD workshop, teachers were found to have increased the number of SSIs that they could discuss and were better able to connect SSIs to STEM content (Minken et al. 119).

sTC

The central goal of social justice education is to empower students to become agents of change (Dimick 991).With respect to pedagogical decision-making, the justice-oriented educator would design instruction with the goal of promoting students to engage in critical reflection on who is advantaged or disadvantaged relative to the issue and to identify opportunities for action to promote change (Dimick 996). In this study, we conceptualize the **social justice domain** through the lens of sociotransformative constructivism (sTc). This framework engages teachers in pedagogical techniques to engage students in considering social power dynamics through the elements of reflexivity, *authentic activity*, *dialogic conversation*, and *metacognition* (Rodriguez 616).

Reflexivity prompts students to elicit and voice their perspective on the SSI and to acknowledge their own privileges (or lack of privileges) relating to the SSI, and how those privileges play a role in resolving the SSI. *Authentic activity* encourages students to engage in inquiry-based learning activities tied to the everyday life of the learners and that mirror professional practices in STEM fields. The resulting ideas generated by the students are shared beyond the walls of the classroom. The element, *dialogic conversation*, refers to the idea that students have opportunities to co-construct knowledge through structured debates and discussions in which students are directed to develop understanding and explore the emotional tone, ideological, and/or conceptual positions of their arguments. Finally, the element *metacognition*

allows students to reflect on their learning experiences and those of their peers in order to improve their own learning and gain more ownership over their own learning.

Teaching with Environmental Justice Issues

Teachers are responsible for developing environmental literacy in their students, and because of the complexity and multi-faceted nature of environmental issues, they can also frequently be labeled as socioscientific issues (Owens 1). Research indicates SSI is a useful framework in environmental education to develop environmental literacy, students' understanding of science methods, and agency. For example, Morales-Doyle described the enactment of a high school chemistry unit that intentionally connected traditional school curriculum for chemistry to a local issue of environmental contamination in Chicago. Findings indicated students developed a deeper understanding of scientific methodologies, promoted student science achievement above and beyond typical school science curriculum, and enhanced student agency to promote a change (1034).

Similarly, Wang et al. found engaging students in discussion of SSI over 17 weeks of instruction enhanced students' environmental awareness, responsibility, and self-efficacy and led to students' notable shift in decision-making "from emphasizing economic development to supporting environmental protection and sustainability" (3). In contrast, Istania found students are rarely provided the opportunity to engage in authentic problem solving related to environmental issues in class, which the researchers connected to low skill in the identification and investigation of scientific issues (22). This further shows that updating the pedagogical approach for teaching environmental science enhances students' learning and their engagement with and ability to resolve environmental issues outside of the classroom. Our study highlights the effectiveness of

PD aimed at designing and implementing instruction using the SSI/sTc framework to increase student learning and agency and unsettle environmental science teaching.

Research Methods

Professional Development (PD)

This study occurred within the context of the first year of a two-year PD aimed at introducing middle and high school science and math teachers to SSI/sTc. The PD is part of a multi-institutional project between five institutes of higher education, a regional teaching network formed to ensure equitable, high quality STEM teaching in the region, and public and private schools. Teachers committed to two years of SSI focused PD and were provided a stipend for participation and funding for classroom supplies and presenting at conferences. Teachers were recruited in cohorts that promoted collaboration, peer learning, and support from like-minded educators. The teachers in this study encompassed eight of the 14 teachers in the first cohort of teachers who selected an environmental topic for the SSI (see table 1).

Table 1: Teacher Participant Information

Teacher pseudonym	Years of Teaching experience	Grade(s) taught	School	SSI Unit Topic
Ms. Smith	32	8-12th	Public Virtual School	Global warming/climate change
Ms. Brown	21	6th	Public Middle School	Water Resources
Mr. Jones	6	11th	Public High School	Climate Change
Mr. Lopez	14	6th	Public Middle School	Plastic Pollution
Ms. Gonzalez	26	11, 12	Public High School	Water Pollution
Ms. Wilson	12	11, 12	Public High School	Electricity

Ms. Anderson	23	6th	Public Middle School	Access to freshwater
Ms. Taylor	15	7-8th	Charter School	Should we get rid of plastic?

The PD included weekly workshops in the fall, biweekly workshops, Professional Learning Community (PLC) sessions in the spring, instructional coaching, which consisted of one-on-one lesson planning meetings and teacher classroom support visits, two Saturday workshops and/or field trips, and an end-of-year conference, which provided teachers with the opportunity to present mini-lessons from their units of study, collaborate with other teachers, and cultivate teacher leadership around SSI. During their participation, teachers designed instructional units using the SSI/sTc framework (see table 2) focused on a topic of their own choice, which they implemented in their classroom.

Table 2: SSI/sTc Instructional Design Framework

1) Exploration of SSI The socioscientific issues are "local and global controversies related to almost any science or mathematics topics. As you explore topics, consider students' interests and select topics with relevance to their lives and the [school's] curriculum" (Zeidler and Kahn 31).
2) Consider issue system dynamics Ask students to consider a system associated with their SSI. The system may include interactions of humans with nature as well as social components such as political, cultural, economic, ethical, health, nature, equity, and religious considerations.
3) Compare and contrast multiple perspectives Ask students to obtain and evaluate information from a range of stakeholders such as environmental activists, politicians, political groups, researchers, scientists, religious organizations, and media.
6) Employ reflective scientific skepticism Teach students to consider the following questions while reviewing their data and sources of information (Sadler et al., 2019): What biases could affect the presentation of information? Who is the author or organization disseminating the information? What is the purpose and/or

methodology for obtaining information? What expertise and/or relevant experience does the author have? Who is disadvantaged/advantaged with respect to the SSI?
7) Elucidate own position/solution Engage students to defend and explain their position and/or propose a solution to the SSI. Ask students to use their data to explain their position and/or solution, explain the strengths and weaknesses of their claims, and identify their personal biases and possible limitations.
8) Reflexivity Providing avenues to elicit and give voice to one's cultural background, moral and ethical stance, socioeconomic status, belief systems, values, education, and skills influence what we consider is important to teach/learn (Rodriguez 600).
9) Authentic Activity sTc is authentic activity that involves inquiry-based, hands-on, minds-on activities that are also socio-culturally relevant and tied to the everyday life of the learner.
10) Dialogic Conversation Provides opportunities for students to voice their own reasons (emotional tone, ideological, and conceptual positions) the speaker chooses in a specific context.
11) Metacognition Provides opportunities for students to use their learning experiences to transform (actions) themselves and others.

Data Analysis

Data sources included: units of study, pre- and post-observation reflections of two focal lessons observed by an instructional coach, and end-of-the-year interviews. To understand the ways in which teachers applied the SSI/sTc framework to unsettle their environmental study lessons, we utilized a combination of inductive and deductive analytic approaches. (See Appendices A and B for examples of teacher developed units and lesson plans, respectively).

The SSI/sTc framework was first used to identify the ways in which teachers incorporated the various elements into their units, with codes including not present, novice, developing, and expert

to reflect different levels of quality. Two research assistants familiar with the project independently analyzed the units of study for the presence of the framework elements. Interrater reliability was 83.3%. Disagreements were resolved through discussion.

The second stage of analyzing the units was more inductive, which allowed for a holistic perspective of how teachers incorporated SSI/sTc into their teaching. Units scoring high on each element of the rubric were re-analyzed to identify exemplary pedagogical approaches. To identify themes, two researchers examined the exemplars to identify salient themes illustrating pedagogical innovation in teaching with environmental justice issues.

The pre- and post-observation reflections and end-of-year interviews encouraged teachers to reflect upon their instructional goals and their fidelity at incorporating the SSI/sTc framework into their teaching. Teachers identified which elements they intended to address within the individual lessons and their level of comfort. This self-assessment was completed before and after the two observed lessons. During the interviews, teachers answered open-ended questions about how their knowledge and instructional practices for integrating STEM teaching with social justice goals evolved and how they would modify their units to better address their goals. Given the exploratory nature of the study integrating SSI and sTc with environmental studies, we developed emergent codes from the written reflections and interviews to capture the breadth of teachers' experiences designing and implementing these units.

Results

The ways in which teachers in this study unsettled environmental studies were diverse and unique, yet all were successful at designing and implementing instruction using the SSI/sTc framework.

First, we present an overview of the degree to which all teachers incorporated the SSI/sTc framework into their units focused on environmental justice issues. Then, we present exemplary practices teachers incorporated into their units to attend to the framework. Finally, we share teachers' reflections on their units during and after implementation to illustrate the ways in which teachers' beliefs and pedagogical practices were unsettled through this professional development experience.

Unit plan analysis revealed the scientific domain was the one in which teachers were most successful at incorporating into their unit of study (2.70), followed by the social domain (2.52), justice domain (2.39), and discursive domain (0.78) (see figure 1).

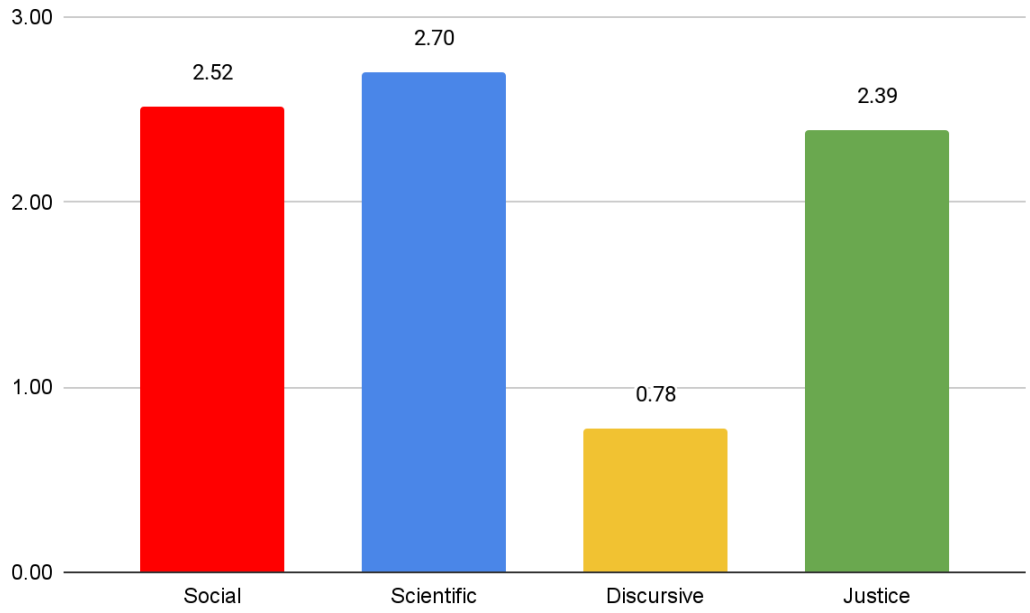

Figure 1. Analysis of 8 Teachers' Units of Study, Stratified by Domains of the SSI/sTc Framework. Each component was scored out of 3 (3=role model, 2=developing, 1=novice, 0=not present or not connected to SSI topic).

Three themes emerged from a more holistic analysis of the units of study exploring how teachers utilized the framework to unsettle their teaching of environmental studies: (1) engaging students in a reflection of lifestyle choices, (2) pinpointing a timely and relevant SSI, and (3) promoting student problem solving and action.

Engaging students in a reflection of lifestyle choices.

Having students connect with the SSI was vital for students' understanding of the science content and for creating a sense of agency for solving the environmental problem. Six teachers challenged their students to reflect on personal lifestyle choices and their effects on the SSI.

Ms. Smith wanted her students to become aware of how their actions may impact the climate and as such, had them complete an ecological footprint quiz to determine the effect of their current lifestyle on the planet. The students had to consider how specific factors such as food choices, housing, and transportation impact the planet. After completing the quiz, the students shared their results and learned ways to reduce their impact. Similarly, Mr. Jones asked his students to compute their carbon footprint, which considers factors including home energy, transportation, and waste. His students were able to view their estimated carbon emissions and steps they could take to reduce their emissions.

Ms. Brown aimed to provide her students with the opportunity to connect with fashion by considering their clothing choices based on their desire to be accepted and trendy versus the environmental impact of fast fashion. She recognized that her students' experiences with closing are different based on family income, cultural or religious background. Ms. Brown wanted her students to be able to "make clothing choices that are more informed and hopefully more aligned

with sustainability and conservation of resources in mind. Moreover, they should be able to identify the factors involved that make it difficult to make more conservation friendly choices, such as cost of final product and equity of availability.

Mr. Lopez wanted his students to recognize that their desire for convenience (using a disposable plastic water bottle) contributes to the local and global problems of pollution of aquatic ecosystems and waste. To explore the differences between tap water and bottled water, Mr. Lopez had his students taste test different waters, as well as use a water analysis kit to test levels of 8 common water quality conditions in order to see which samples are safer to drink - bottled or from the tap. He connected all of this to pollution of the watershed where the school is located.

Ms. Anderson's students examined their personal water usage by documenting all the ways they use water daily. They considered why water is a necessity and what individual changes they could make to reduce the amount of freshwater they use. Finally, Ms. Taylor had her students consider the convenience of using single-use plastics and ways to avoid it. She challenged her students to document the waste they created each day at lunch to determine what type of trash they produced, what happened to the trash when it was thrown out, and how trash can be better managed. She had her students brainstorm ideas for reducing the amount of trash they personally create and strategies for encouraging others to use resources wisely.

Pinpointing a timely and relevant SSI

Six of the eight teachers in this study chose an SSI that was authentic and well-timed for their students. The teachers were knowledgeable about their learners and, as such, picked an SSI directly relevant to the lives of students. For example, Mr. Lopez chose an SSI connected to the lives of

his students – the use of plastic water bottles, after noticing that many of his students used plastic water bottles daily. Mr. Lopez saw an opportunity to connect the required science content to the lives of his students. Similarly, teaching teenagers, Ms. Brown recognized the importance of fashion in the lives of her students and decided upon fast fashion for her SSI. Her students explored the topic by examining the global controversies behind the issue and how the fashion industry and science intersect. She reflected on the importance of the issue stating, “It is an SSI issue because many clothing brands that are manufactured and marketed to last long are costly and might be unaffordable for everyone.” Hence, she recognized the need for her students to buy clothing that was both fashionable and affordable, yet often at the expense of the environment. Ms. Taylor wanted her students to understand the environmental impacts of disposable plastic. She recognized her students were receiving conflicting information about plastic use — their city banned plastic bags, yet the school cafeteria still provided disposable plasticware and bottles.

Ms. Gonzalez's unit of study centered on the Delaware watershed, the local watershed where her students live, which “is a semi-local issue in which the waters have been claimed to be the most polluted in the US.” She had her students “look deeper into the reason for this issue to determine the root cause.” Focusing on a serious environmental issue within the local watershed established relevance to the lives of the students. Similarly, Ms. Wilson chose an SSI of local relevance: renewable power distribution. She stated, “This lesson series looks at the inequities in power distribution and power restoration in their city. It also looks at the impact of adjusting renewable and nonrenewable sources to change that impact.”

Ms. Anderson chose an SSI directly relevant to the lives of her students – freshwater access. She recognized the importance of this issue to her students because her students take for granted access to freshwater – they simply need to turn on the faucet. Yet, some of her students have experienced firsthand flooding in their city or have families who live in other countries where access to fresh water is not guaranteed. Furthermore, Ms. Anderson had her students read statements about water issues and decide if each was an individual, local, or global issue, thus strengthening the connection of water as both a local and global issue.

Promoting student problem-solving and action.

Teachers unsettled traditional environmental classes by designing and implementing instruction using the SSI/sTc framework. As such, each of the teachers promoted students to solve environmental problems and take action within their own schools and communities. This was accomplished through mock debates, community awareness activities, or projects to improve their schools or communities.

Mock Debates. Teachers offered mock debates in their classrooms to help students learn about the SSI while also developing critical thinking, research, and problem-solving skills, as well as exploring perspectives different from their own. For example, Mr. Jones had his students conduct a mock United Nations Environmental Justice debate in a unit of study about climate change. Students were randomly assigned into roles as various stakeholders including government representatives from first and third-world nations, and representatives and workers from both the fossil fuel and alternative energy industries. The groups researched climate-related issues from the perspective of their stakeholder group followed by debates with two different stakeholder groups. Similarly, the students in Ms. Wilson's science class studied the inequities in power distribution

and power restoration in a mid-Atlantic city. The students debated whether students should have priority with USB stations on public buses before and after school hours. Ms. Wilson recounted that her students confided that they change how they travel and where they go to charge their phones. Thus, Ms. Wilson used this knowledge of her students' behaviors to leverage the debate. Ms. Brown also had her students debate their position for fast fashion or for sustainable clothing production considering the need to provide equitable access to clean water for everyone.

Community awareness activities. For teachers in this study, it was important that their students shared with others what they learned about the environmental issue. This was demonstrated in a variety of ways including posters, presentations, and a t-shirt design. For example, Ms. Anderson had students examine the environmental impact of road salt on freshwater resources in their city. After considering the multiple perspectives on the issue, the students defended their position through a written reflection on whether road salt should be used on city roads considering the benefits and challenges. They then created a poster to share their position with those of opposing viewpoints. Ms. Taylor provided her students with opportunities for *metacognition* including creating an educational poster about recycling to post in the school, creating a public service announcement video about the importance of recycling, and making announcements implementing recycling in the school. A unique strategy to spread the word about climate change, Ms. Smith's students designed a t-shirt, which was given to each student to wear to teach their families, friends, and neighbors about what they learned about climate change in the local area.

Improvement projects. Two teachers strived to encourage their students to become agents of change – to take their new knowledge outside the classroom in hopes of helping to solve complex

environmental problems and create change. Ms. Brown wanted her students to reflect on their own clothes and family needs and think about how their consumerism could impact the environment. They can then make choices to change their own behavior to help keep water fresh. To empower her students and make real change, Ms. Brown conceived having her students create a clothing recycling program to upcycle, recycle, or downcycle clothing to help keep clothing out of landfills and ultimately help keep water fresh. To encourage *metacognition*, Mr. Lopez engaged his students in a service-learning program with Terracycle to begin an upcycling program at their school. "As part of the program, 6th-grade students partner with other homeroom teachers of younger kids to educate them about recycling. The 6th graders will instruct those students on the following questions: What is recycling? Why is it important? What can be recycled? How does recycling work? The 6th-grade students could make signs, posters, a presentation, read a book, etc. for a month-long program."

Teachers' self-reflection on implementation.

Teachers had an opportunity to reflect on their knowledge and instructional strategies related to teaching with the SSI/sTc framework through pre- and post-observational surveys, including open-ended questions and an end-of-the-year interview. Findings presented below address their self-assessment of skill for teaching with SSI/sTc, how they integrated traditional science content within the SSI/sTc framework, and lessons learned from implementing the unit for the first time with their students.

Teachers assessed themselves as novice (rating = 1), developing (rating = 2), or role model (rating = 3) for each element of the framework (see figure 2).

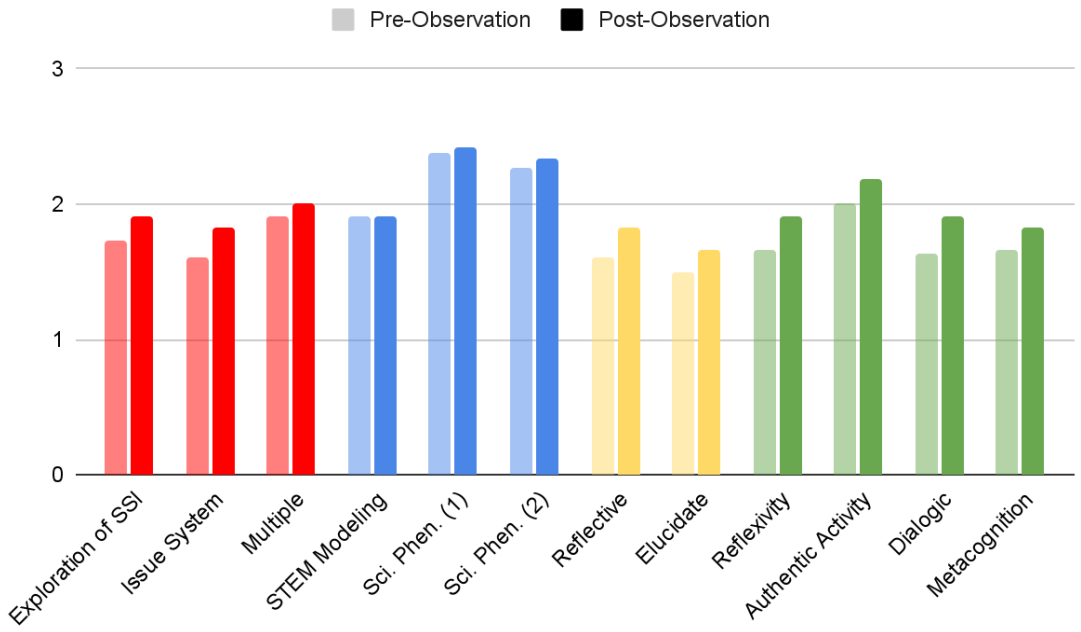

Figure 2. Teachers Self-reported Ratings for Effectiveness of Addressing Each Element of the SSI/sTc Framework.

Overall, teachers felt most confident about their knowledge and instructional strategies for implementing the scientific domain. Since each of the teachers in this study is a science educator, it follows that they would feel most confident about their ability to implement the scientific elements of the rubric. Through self-assessment, 33.3% rated themselves as role models, 55.6% as developing, and 11.1% as novice. For the social domain, teachers rated themselves as role models (8,3%), developing (75%), and novice (16.7%). Teachers rated themselves as role models (18.8%), developing (60.4%), and novice (20.8%) for the justice domain. Finally, teachers considered themselves as developing (75%) and novice (25%) within the discursive domain, with no teachers rating themselves as role models.

Integrating SSI and SJ with STEM content.

While teachers utilized different approaches to the task of unsettling environmental studies as they developed and implemented a unit of study using the SSI/sTc framework, they each strived to have an overall goal of making the STEM content relevant to the lives of their students and helping their student develop the skills and knowledge necessary to solve pressing environmental issues. This was evident in teachers' reflections on the overall goals of their units.

Ms. Smith reflected, "I want my students to understand the multiple perspectives, numerous issues, and complications related to climate change. Students need to realize the complexity of global warming as it relates to business, politics, science, inequities, and health impacts related to global warming. Additionally, I want the students to understand what the greenhouse effect is, what global warming is, and the local, regional, and global impacts of climate change. In addition, I would like the students to realize the social injustices that exist surrounding climate change and for them to become advocates of change in their communities." Ms. Brown wanted her students to "understand the environmental effect of Fast Fashion on the equity of water availability." Similarly, Mr. Jones wanted his students to be able to "evaluate a video model of the greenhouse effect, identifying strengths, limitations, and ways to improve. Students will begin to understand the Global Impact of climate change including how it affects different countries and populations differently." These examples demonstrate the teachers' commitment to increasing student content knowledge, while also promoting their ability to think critically about their connections to the environmental issue.

However, teachers did struggle to successfully integrate social science across the unit. It became evident that teachers had lessons that were more science focused and lessons focused on social,

justice, or discursive elements of the framework. Before an observed lesson, Mr. Jones shared that he wanted his students to “Demonstrate ability to evaluate a model. Answer questions related to the Global impact of climate change.” Similarly, Mr. Lopez asked his students to “use a water analysis kit to test levels of 8 common water quality conditions IOT see which samples are safer to drink - bottled or from the tap.” Ms. Brown offered an SSI lesson to help her students “understand the equity of having access to fast fashion vs more sustainable fashion.” Ms. Taylor wanted her students to have an "aha" moment at the end of the lesson after we all have done our research, and conversations surrounding single-use plastics and be able to connect it all to why we should stop using them, but more importantly - how do we accomplish this goal? These specific lesson goals demonstrate that teachers struggled to successfully unsettle their environmental science teaching. Viewed alongside their self-reported ratings on their confidence in the various elements of the rubric (see table 3) emphasize a need for instruction and practice with teaching with an SSI/sTc lens. What is also promising is that teachers recognized and were open to engaging more with the framework and continuing to revise their units of study for future implementation.

Table 3

Teachers Self-reported Ratings for Effectiveness of Addressing Each Element of the SSI/sTc Framework.

	Pre-Observation	Post-Observation
Exploration of SSI	1.7	1.9
Issue System Dynamics	1.6	1.8
Multiple Perspectives	1.9	2.0
STEM Modeling	1.9	1.9
Sci. Phen. (1)	2.4	2.4
Sci. Phen. (2)	2.3	2.3
Reflective Scientific Skepticism	1.6	1.8
Elucidate Position/Solution	1.5	1.7
Reflexivity	1.7	1.9

Authentic Activity	2.0	2.2
Dialogic Conversation	1.6	1.9
Metacognition	1.7	1.8

Lessons learned

The teachers reflected on individual lessons, as well as the implementation of their entire unit. They considered what was successful and what could be improved, what steps they could take to improve their units, and what support they needed to do so. Some teachers offered general remarks and areas for improvement such as Ms. Smith who reflected, "I learn from my mistakes!!!!!" Time was an issue described by teachers. When reflecting on a specific lesson, Ms. Anderson shared, "The concept was there but I was racing through the lesson. I need to spend more time on certain ideas. I needed to give students more time to discuss." Ms. Brown also considered time an issue, "I would like to have the students finish the lesson as we have been interrupted a great deal over the course of implementing the unit."

Other teachers acknowledged specific areas for growth. Mr. Jones remarked, "I need to get some advice and input on ways to implement these skills [debatable issues, multiple perspectives, and dialogic conversation]" into his teaching, while Ms. Gonzalez wanted to "Continue to develop and practice implementing socioscientific issues." Ms. Taylor also saw an area for improvement within her unit of study. When thinking about changes she would make next year she stated, "Next time I would have more articles and talk about the impacts of it. So, we talk a bit about it, but it was like more verbalized than it is like a reading article."

Teachers' reflections on their experiences designing and teaching environmental science units guided by the SSI/sTc framework revealed that teachers struggled to integrate SSI and social justice across their curriculum. While teachers acknowledged that teaching with an SSI/sTc framework was difficult, they were open to improving their knowledge and teaching strategies to continue unsettling their environmental science classes.

Discussion and Conclusion

The following research questions guided this study: (a) How did teachers unsettle environmental studies by designing and implementing instruction using the SSI/sTc framework? (b) To what extent did teachers' reflections on their teaching indicate an unsettling of teaching environmental studies? Findings indicate that teachers were successful in incorporating authentic, inquiry-based learning experiences grounded SSI and SJ into their environmental science lessons because of participation in the PD. This finding supports the work of a similar study that found pre-service teachers needed focused SSI coursework and professional development to become effective at implementing SSI in their lessons (Johnson et al. 3).

While the teachers did unsettle their environmental studies units by incorporating aspects of the SSI/sTc framework, there was a discrepancy in teachers' planned units and their actual implementation, indicating: 1) teachers struggled to integrate the SSI/sTc framework across their unit and as such often taught more traditional "science" lessons and SSI or SJ focused lessons, and 2) shifting teachers' traditional scientific mindsets toward a more transformative and critical stance to "unsettle" environmental science will require more support. Each of the teachers described how their knowledge and teaching practices related to SSI and SJ changed as a result of participating in the PD; however, they also acknowledged that teaching in this manner is difficult and allows

for continued learning. Finkel argues that to make science relevant to the learner, we must prepare teachers who "bring a social justice lens to bear on their teaching and who can develop curriculum and facilitate classroom experiences that engage all students to help them see the relevance of science in their daily lives" (41).

We explicitly supported teachers in addressing these two challenges in the second year of the PD. First, we introduced new pedagogical strategies that helped teachers more effectively integrate the SSI with the environmental content knowledge across the unit to create a more cohesive and student-centered learning experience. For example, we introduced the STAR chart as a strategy to help students visualize the different components of the social system, notably historical, cultural, economic, and political elements (Peel et al. 52). Second, we introduced strategies to help teachers forefront issues of social justice embedded within the issue. A key example is the Problem Tree, by which students begin by identifying everyday manifestations of the issue in their lives (leaves), infer the common attitudes that uphold and reproduce these daily impacts (trunk), and the root ideologies and societal structures that support these attitudes (Tuck et al. 63). For both the STAR chart and the Problem Tree, teachers were able to post and document new ideas and changes in class thinking throughout the unit, connecting the social and scientific systems in their understanding of the SSI. Furthermore, we supported teachers in making more authentic connections between their unit and the school and broader community through an activity of mapping community assets, a process of identifying key stakeholders and allies to support student learning beyond the walls of the classroom (Marco-Bujosa et al. 56).

Being that this study reports on year one of a two-year PD, findings indicate the teachers gained knowledge and instructional strategies that allowed them to unsettle and transform their pedagogy after one year. They also indicated the intention of continuing to learn and incorporate SSI and social justice into their curriculum. In the second year of the PD programming, we explicitly scaffolded these skills. Thus, PDs such as the one at the focus of this study can be used to introduce teachers to teaching with an SSI/sTc framework, ultimately making STEM learning authentic and relevant to the students' lives and encouraging them to become agents of change in solving environmental issues.

Limitations of Study

The teachers in this study were all self-selected to participate in the PD and were geographically concentrated in a large urban area in the eastern United States, which affects the generalizability of our findings. Our data was limited to teachers creating and implementing environmental studies unit plans using an SSI/sTc framework and thus may not represent teachers who developed non-environmental studies-focused units. Similarly, the data analyzed in this study is that of the teachers and may not fully represent the experiences of their students. While our findings are promising, future research endeavors can include a) a follow-up study to learn if teachers change their teaching practices to incorporate SSI and SJ across their curriculum; and b) a longitudinal study to determine if the teachers continue to use an SSI/sTc framework to unsettle their environmental studies classes.

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Appendix A: Sample Unit of Study

Climate Change is Affecting Everyone, Should Everyone Share the Responsibility Equally?

Grade/ Grade Band: 11	**Topic:** Climate Change	**Series of** __10__ **lessons**

Brief Lesson Description: This unit uses the 5E unit design.
Students will learn about the impact of the changing climate on a global and local scale. Students will investigate how greenhouse gases contribute to warming temperature and the inequitable harms caused by climate change. Throughout the unit students will reflect on how the responsibility of addressing the causes and harms of climate change should be shared.
This unit is expected to take approximately 4 to 5 weeks.

Description and Explanation of SocioScientific Issues (SSI):
Socio Scientific Issue: How should the responsibility of addressing causes and harms of climate change be shared?

The industrial revolution, which was fueled by burning fossil fuels and extensive deforestation, brought rapid development, new technologies, and improved standards of living for most of the world. Years of burning fossil fuels, however, have resulted in an atmosphere filled with heat-trapping gases leading to a warming planet and a changing climate. The world has not benefited equally from these advancements and the world is not being affected equally by the problems of a changing climate, but the problem requires a global solution with a significant economic cost.

It would be easy to simply blame the industries and nations that produce and burn the majority of fossil fuels, since they are getting rich using cheap energy, but we have all grown dependent on fossil fuels and the products provided by these industries. Fossil fuels are also still the cheapest energy source for developing countries who want to grow their economies and provide improved living standards for their citizens. Many also depend on jobs within the fossil fuel industry.
A change to a non-fossil fuel world economy will take time and money, causing disruptions to many lives. However, not addressing the problems caused by fossil fuels will endanger many, especially those without the means to adjust to a changing climate.

Students will have to wrestle with different perspectives to form their own opinions on how the responsibility for addressing the causes and harms of climate change should be shared.

Specific Learning Outcomes:
Students will be able to explain the causes and harms of climate change.
Students will be able to evaluate graphs to draw conclusions.
Students will be able to consider perspectives of various stakeholders and draw their own conclusions.

Narrative / Background Information

Prior Student Knowledge: Basic understanding of the properties of water, weather, climate and the related vocabulary words.

Science and Engineering Practices	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Developing and Using Models. **Analyzing and Interpreting Data**	**ESS3.D: Global Climate Change** Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. (HS-ESS3-5) **HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.**	**Evaluating patterns** **Energy and matter** **Cause and effect** **Systems and system models** **Stability and Change** **Scientific argumentation**

Students' Prior Conceptions:
In general students know that climate change is a serious issue that can cause serious problems and often feel anxious, resigned, or have a general indifference due to their lack of understanding of the specific problems and how they are being affected personally.

Sociotransformative constructivism (sTc):
1. Explain how this lesson provides students with the opportunity to choose and connect with a topic of local importance.
   a. How is the issue important to students?

   b. How is the issue evident in students' locale/community?

c. Which student funds of knowledge are tapped in addressing the issue?

d. Will the students have opportunities for authentic change in their community?

Students are aware that climate change is happening and that their futures are in danger, but they don't really understand what the direct impact will be on their lives or what they can do to stop it. Students often express their anxiety over the problem.
Students are already experiencing the effects. Philadelphia has experienced flooding from extreme rainfall events and excessive heat during the summer.
Students are also aware of various societal inequities that have created barriers to improving their social and economic situations.
This unit will help students to make connections between social inequities and the inequities of harm brought by climate change and will give them the knowledge they need to contribute to the mitigation of this global and local issue.

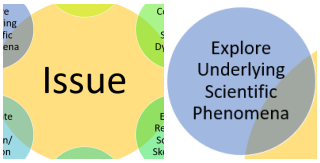
2. How do students' cultural background, socioeconomic status, belief systems, values, education, and skills influence what you consider is important to teach/learn in this lesson?

Students in the class predominantly represent minority populations and live in economically disadvantaged neighborhoods within the city of Philadelphia. Students often feel powerless to change their circumstances. This lesson will help empower students to make a well thought out, evidence based argument, and allow them to share their views and attempt to influence an audience.

LESSON PLAN

Background knowledge: Students should have a general understanding of weather and how to evaluate graphs.

ENGAGE: Establish relevance - help learner determine need of learning new concepts



sTc: "Why am I learning about this topic?"

Lesson 1

2 class periods:

Objective: Students will participate in dialogic conversation by sharing and explaining their position on the topic of climate change

Students will evaluate evidence that can support a position.

Students place a sticky note with their name on an agreement line based on how strongly they agree or disagree with the statement: "Climate change is real and primarily caused by human activity."

Placards of strongly agree, agree, neutral, disagree, and strongly disagree are to be placed along a wall. Students place sticky notes with their names along the wall according to their position.

Students with different positions are then asked to explain their position

Part 1: Is climate change real and caused by human activity? Students will be shown 2 video clips. (Video clips require a free Edpuzzle account).

- Clip #1 - EdPuzzle Clip - The Great Global Warming Swindle created by an individual in England pulling from sources such as the Discovery channel and the Environmental Defense Fund.
- Clip #2 - EdPuzzle Clip - Climate Change Impacts Adaptation and Vulnerability Created by IPCC, International Panel on Climate Change

After watching the videos, students will work in small groups to complete a T-chart with one side.

Evidence for	Evidence

Climate Change due to Human Activities	against Climate Change due to Human Activities.

Students discuss how they identified evidence.
Students revisit the agreement line by having students move their post-it to their new position.

Discussion questions:

1) What led you to where you are on the agreement line?
2) What evidence influenced you the most and why?
3) What information did you hear that was not convincing and why?
4) What other information would you want to be able have a stronger opinion?

Part 2:
Objective: Students will formulate, work with, and use their own questions, in order to activate their curiosity and make connections to prior knowledge. .
Student group will then follow the Question Formulation Technique (QFT) process to generate and refine questions they have about climate change. The two videos previously watched will be the focus of the QFT.

EXPLORE: Engage students in the content - help learner understand concepts, process/procedures, facts or principles

sTc: "Why am I learning these concepts in this way?"

Lesson 2

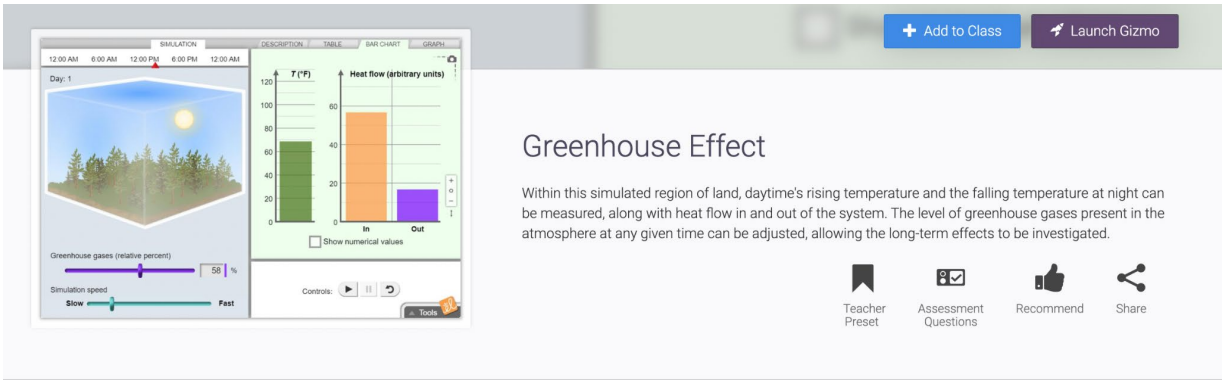
Exploring the Science
Day 1

Objective: Students will be able to examine information in a reputable website in order to explain whether or not human activity is to blame for Climate Change.
Students will work in small groups to complete a web quest on climate change. (Click Here for a PDF version of Webquest) The web quest begins and ends with students rating their opinion on how much impact that humans have had on the climate. The web quest is intended to help students build their background understanding of the causes, effects, and evidence of climate change.

Lesson 3

Day 2

Objective: Students will be able to explain why some amount of greenhouse gases are necessary for life on earth.



Students will complete a Gizmo Greenhouse gas simulation activity (Gizmos are a tool within the Explore Learning web platform. This lesson requires a license for Explore Learning.).
Students use the web tool to answer questions in a Google Document. (link to Part 1 Google Document)

Lesson 4

Day 3 - 4

Objective: Students will be able to create and explain a model of the greenhouse effect.
Students are given a review of scientific modeling (link to slide deck).
Students work in a small group to create a two-dimensional model of the greenhouse effect on poster paper.
Posters will be displayed around the classroom. Student groups will rotate around the room

in a gallery walk to view posters from each group. Students will have 3 minutes at each poster to post post sticky notes with what they like about the model, and ideas for improvement. Groups review the sticky notes with feedback and complete a Model Feedback Reflection Form

Lesson 5

Day 5 -6

Objective: Students will evaluate information provided in a video and identify perspectives of different stakeholders related to climate issues.

Student groups watch the documentary, "Before the Flood" in a jigsaw activity. Each student in a group will watch one 15 minute section of the video and answer questions on a worksheet (link to worksheet). Students will work with other students who watched the same segment and discuss their answers with one another. Videos are on Edpuzzle (Link to EdPuzzle Video - Group 1, Group 2, Group 3, Group 4, Group 5

A spokesperson from each group will share answers for their section with class so that all students will have complete set of answers for their worksheet.

Students will participate in a whole class discussion on who is being harmed and how by climate change. Responses will be captured on two column chart with one column for who is being harmed and the other column how they are being harmed.

Students then revisit the statement "Climate change affects everyone, therefore everyone should share the responsibility equally." How strongly do you agree or disagree with this statement? Students will repost their post-it notes with their names. Randomly selected students who changed their position will be asked to explain what influenced them to change their minds.

Lesson 6

Day 6 to 7

Objective: Students will evaluate maps, and investigate local impacts and inequities of climate issues.

Students will complete a Nearpod lesson on Climate Change in Philadelphia (link to Nearpod preview). A Nearpod account is needed to share lesson with students. The lesson will provide

practice for evaluating GIS images and making connections between summer temperatures, tree cover, income, and asthma rates.

Lesson 7

Day 8 to 10

Objectives: Students will investigate how carbon dioxide levels vary by different human activities.

Student groups will design a scientific investigation into human activities that produce carbon dioxide. In small groups, Students brainstorm a list of potential sources of carbon dioxide and how each source could produce different amounts of carbon dioxide. Students then design their investigations focused on one source of carbon dioxide. Possible sources of carbon dioxide to investigate: respiration of people of different heights or weights, exhaust of different types of cars, gas ovens at different heat settings.

1. They will then plan a scientific investigation to determine the amount of carbon dioxide that each source emits under different study conditions. .
2. Data from their investigations will be graphed and data evaluated to determine the what conditions from each process produces the most and least carbon dioxide

Link to worksheets students can use to design and evaluate their investigation

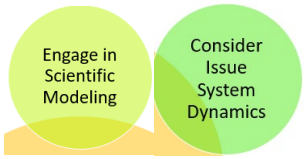
Part 1 - Scientific Investigation Planning Sheet

Part 2 - Scientific Investigation Planning Sheet

Part 3 Scientific Investigation Evaluating Test Results

Laboratory Procedure Peer Review

EXPLAIN: Improve understanding - help learner express new learning and provide guidance



Lesson 8

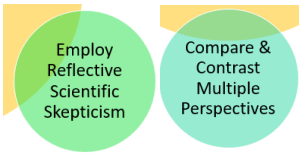
Day 11 to 14

Objective: Student will prepare for a mock UN Environmental Justice Debate.

Students will randomly select roles as various stakeholders: Government representatives from 1st and 3rd world nations, Fossil Fuel Industry reps and workers, Alternative energy

industry reps and workers.
Groups will research climate related issues from the perspective of their stakeholder group. Groups will debate over climate issues. Each group will participate in two debates with two different stakeholder groups.
Link to Instructions

ELABORATE: Construct new learning - help learner apply prior learning and acquire new



sTc: "What control [voice] do I have in how to proceed?"

Lesson 9

Day 15 to 26
Objective: Students will create a video as reporters investigating the inequities around one climate change related issue. Link to project description

EVALUATE: Assess learning - help learner measure learning against its corresponding goals

sTc: "By what other method(s) can I learn this subject matter best?"
Students will be evaluated throughout the unit on the quality of their work and depth of understanding.

Elaborate Further / Reflect: Enrichment:

Lesson 10

Day 27
Objective: Students will determine their own carbon footprint using the EPA Carbon Footprint Calculator, https://www3.epa.gov/carbon-footprint-calculator/

Resources:

US EPA, Climate Change Science, https://www.epa.gov/climatechange-science, accessed Feb 4, 2022.
NASA, Global Climate Change - Vital Signs of the Planet, https://climate.nasa.gov/, accessed Mar 30, 2023
United Nations Act Now, https://www.un.org/en/actnow/ten-actions, accessed Mar 30, 2023
EPA Carbon Footprint Calculator, https://www3.epa.gov/carbon-footprint-calculator/, accessed March 30, 2023
Climate Change 2022: Impacts, Adaptation & Vulnerability, https://youtu.be/SDRxfuEvqGg, Accessed https://youtu.be/SDRxfuEvqGg

Appendix B: Sample Lesson

Teacher: Ms. Brown
SSI: Fast Fashion, is it worth its weight in water?

Brief Lesson Description: In this lesson, we will examine fast fashion and understand its effect on the equity of fairness in using water for what you want and need. We will also look at if fast fashion takes away from everyone's ability to have access to clean water.

Description and Explanation of SocioScientific Issues (SSI):
Fast Fashion can be described as the phenomenon of "cheap, trendy clothing that samples ideas from the catwalk and celebrity culture" (https://goodonyou.eco/what-is-fast-fashion/) The Industrial Revolution happened, making clothes cheaper and cheaper to manufacture and enabled trend cycles to sped up. People shopping for clothes went from happening seasonally or when they were outgrown, to happening as a hobby as the clothes trends keep changing. People went from occasionally shopping for clothes, to dressing
Some fast fashion big companies are: UNIQLO, GAP, Primark, TOPSHOP, Zara and H&M, which is the oldest. (https://goodonyou.eco/what-is-fast-fashion/)

Fast Fashion is more affordable because it is manufactured using cheap labor, materials and pays laborers low wages. The quality of the clothing is not sustainable or made of a quality that is long lasting.

It is an SSI issue because many clothing brands that are manufactured and marketed to last long are costly and might be unaffordable for everyone. This brings up the question of fast fashion being equitable; moreover, is it as eco-friendly as clothes made to last over time as those are more sustainable for the environment as they don't follow trends and may not be as disposable as the trendy clothes.

Sample Lesson: Fast Fashion vs. Sustainability Part 2
Objective:

- Students will identify key points in assigned articles to determine how the article supports, doesn't support, or is just giving facts about Fast Fashion, in order to create a Powerpoint/Google Slide presentation debating their position of "Is Fast fashion equitable for all people having access to clean water". Students will accomplish this task by completing a graphic organizer.

Teacher will:

- Teacher will have students count off as they enter the room. The students will sit at the table that corresponds with their number.

Students will enter into the classroom and take their seats (2 minutes)

- Teacher will say "Students, today we will be reading some articles to help us better understand how Fast Fashion impacts our water supply and natural resources."

- But first, we will watch this video https://www.youtube.com/watch?v=QojPDlEWL9Y "**What is Social Justice?**"
- Turn and Talk to your group, discussing what was the problem in the video, and how the issue was resolved"
- Share out of 2 or 3 of the comments.
- Teacher will say "I am going to give you a main idea graphic organizer. As you read the article, please fill out the organizer. Please keep in mind the video we watched, and make connections about equity in your readings. Be prepared to share your findings with the class. **(6 minutes)**

Students read the article and fill out the main idea graphic organizer (20 minutes)

- Teacher will have students take out their ChromeBooks and tell students "Now we are going to work in our groups and add our information on a slide to share with the rest of the class. Work in your group to determine what information will be included on the slide.
- Teacher will open the link and project it on the Smartboard https://docs.google.com/document/d/14rqc2bR8u5khX8Jg5XRTaCq2xP6uGHUNuqMcqCEu3wY/edit?usp=sharing

Students fill out the main idea graphic organizer in the document (10 minutes)

- Teacher will say "Now, take a few minutes to read over some of the other articles main points"

Students fill out the main idea graphic organizer in the document (5 minutes)

- Teacher will say "We will now do an exit ticket. Please complete the exit ticket based on what you have learned from another article Please turn in your exit ticket as you leave the classroom"

Students will answer Exit Ticket Day 3 and turn it in to teacher on the way out of the classroom (3 minutes)

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