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Developing student agency through authentic application of socioscientific issues in STEM classrooms

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ABSTRACT This study explores the experiences of STEM teachers who participated in professional development (PD) workshops focused on supporting the use of a socioscientific issues (SSI)/socioTransformative constructivism (sTc) framework as an avenue to incorporate SSI into lessons and empower students to become agents of change outside the classroom. The following research question guided this study: In what ways, if any, do participant teachers foster authentic, active engagement and student agency in their STEM classroom following participation in an SSI focused professional development program? Thematic analysis was used to identify, analyze, and interpret the data. The findings demonstrate that teachers were successful in providing students with authentic learning opportunities in which students developed a sense of agency by moving beyond traditional STEM content, moving beyond the classroom walls, and moving inward within the school. Understanding the ways in which teachers engage students in authentic learning and foster student agency within an SSI unit of study has implications for scholars and researchers who provide PD to teachers.

Keywords: *Authenticity, Socioscientific issues, Sociotransformative constructivism, Student agency*

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INTRODUCTION

Current reforms in science, technology, engineering, and mathematics (STEM) education call for teachers to provide hands-on and authentic learning experiences that encourage students to learn about and engage in real-world problems (Parker et al., 2016). Such learning experiences promote disciplinary core ideas, science and engineering practices, and cross-cutting concepts that are of central importance to STEM learning (National Research Council, 2012); however, some researchers and educators have argued that these projects often fall short in educating students on other components of solving real-world problems. Zeidler et al. (2005) asserted that science, technology, society, and environment (STSE) approaches are failing to address students' ethical and moral development. Ten Dam & Volman (2004) argued that instructional strategies must focus on critical thinking as a skill for civic engagement and citizenship education. Similarly, Dauer et al. (2021) found that students' self-efficacy, attitudes, and skills toward solving complex SSI problems increased after participating in a science course structured to develop science-informed decision-making skills. Incorporating socioscientific issues (SSI) provides a framework with the potential to address issues of moral reasoning and civic engagement while simultaneously addressing student engagement in STEM content, science and engineering practices, and cross-cutting concepts (Marco-Bujosa et al., In Review).

SSI in STEM classrooms provides a meaningful way for students to engage with STEM content and an effective avenue to highlight moral sensitivity and ethical implications when presented with SSI scenarios (Zeidler & Sadler, 2010). SSI are real-world science issues that are controversial and ill-structured, have moral and ethical aspects, and provide students with a context for learning in both curriculum and community contexts (Chowdhury et al., 2020). For example, the study conducted by Taşdemir and Yildirim (2016), their study found that while students had some understanding of the scientific aspects of genetically modified organisms, their moral reasoning regarding their decision-making was influenced by factors such as potential risks and benefits. Similarly, Herman et al. (2021) found that in exploring environmental topics, students were better able, through their engagement with SSis, to weigh scientific evidence situated within ethical and sociocultural considerations.

SSIs can also be used to promote civic engagement by emphasizing factors such as empowering students and involving them in decision-making processes (Grudens-Schuck & Sirajuddin, 2016). This can also mean empowering communities to participate in impacting their local environment in positive ways, which fosters a sense of ownership, responsibility, and active participation in solving community problems (Golumbic & Motion, 2021). In the classroom, Albe and Gombert (2012) investigated how students engaged in communication, argumentation, and knowledge application during a citizens' conference simulation focused on global warming. SSI discussions fostered debates among students on energy choices, economic and political considerations, and scientific and technological developments related to harnessing renewable energy sources, which suggested that they were able to connect scientific concepts to the real-world issue.

Endeavors have been made over the past several decades to help teachers develop their pedagogical content knowledge in order to teach SSI in their classrooms (Minken et al., 2021). The research study conducted by Macalalag et al. (2019) provided evidence that experienced elementary teachers were open to teaching controversial topics like environmentalism. Their motivation stemmed from fostering awareness and social responsibility in students and from their own interest in the subjects. This study also highlighted the importance of professional development (PD), as teachers connected science with engineering practices, as they explored cultural aspects of SSI, and as they integrated SSI with civic engagement into their curriculum. Friedrichsen et al. (2020) described the successes and challenges science teachers encountered while enacting co-designed SSI units. Specifically, the co-design process helped teachers develop a deeper understanding of integrating both scientific concepts and social considerations, encouraged teachers to explore new teaching strategies (e.g. incorporate discussions about social impacts on science), and increased confidence in their ability to teach SSI-based pedagogy. However, they struggled to balance the time spent on SSI activities and had concerns about facilitating open discussions on controversial issues. The current study explores data drawn from a large-scale SSI

focused PD in which participant STEM teachers incorporated SSI into their teaching using a framework combining SSI and socioTransformative constructivism (sTc) to make sense of the social justice aspects of their selected SSI topics. In order to better understand the challenges described and how teachers fostered student agency while teaching with the SSI/sTc framework, we explored the experiences of several teachers participating in an intensive PD program and sought to answer the following research question: In what ways, if any, do participant teachers foster authentic, active engagement and student agency in their STEM classroom following participation in an SSI focused professional development program?

REVIEW OF RELATED LITERATURE

Socioscientific Issues

As described, SSI are debatable problems that are founded in science but also incorporate both moral and ethical perspectives such that they cannot be resolved through science alone (Ratcliffe & Grace, 2003). Incorporating SSI into the classroom can enhance STEM learning and scientific skill development by encouraging students to use personal experiences, knowledge, and cultural background to consider moral and ethical problems relevant to their daily lives (Zeidler, 2014). While the benefits of incorporating SSI into the curriculum are well-documented, teachers may lack the knowledge, skills, and support needed to be successful in this endeavor (Rodriguez, 2005). PD and SSI focused coursework can be effective at providing teachers with the knowledge, resources, and experience to develop the necessary skills for effective SSI implementation (Johnson et al. 2020).

To be successful in incorporating SSI into the curriculum, teachers must feel confident in not only their subject matter knowledge, knowledge of their students, and teaching practices but also the specific pedagogical content knowledge (PCK) related to SSI instruction (Lee, 2016). Kinskey and Zeidler (2024) found that teachers actively worked to develop lessons with which the students could connect, ultimately increasing the teachers' confidence and knowledge of SSI focused pedagogy. Similarly, Kahn (2021) found teachers reported satisfaction after witnessing students authentically engage with STEM content when delivered with an SSI focus. In the study conducted by Macalalag et al. (2019), participating in PD and coursework helped teachers develop their PCK toward engaging their students in evidence-based reasoning on real-world issues. Moreover, the PD provided teachers with opportunities to explore and develop new teaching strategies for SSI instruction, including facilitating classroom discussions, incorporating role-playing activities, and utilizing technology-based resources. In a follow-up study conducted by Minken et al. (2021) involving mostly secondary science teachers, findings demonstrated positive improvements in all aspects of teachers' SSI-related PCK throughout the PD. In particular, teachers demonstrated a better understanding of how to identify debatable and student-relevant issues, incorporate scientific explanations with reflective skepticism, and consider multiple perspectives when engaging in SSI contexts.

In addition to learning how to effectively develop and implement SSI instruction, researchers have documented challenges for teachers beginning to learn how to incorporate SSI into their lessons. For example, Lee (2022) saw that prospective teachers in South Korea struggled to balance meeting the curriculum requirements with the need to address students' interests and concerns regarding the selected SSI. Moreover, they expressed a need for skills in facilitating classroom discussions on complex and potentially controversial issues, differentiating personal beliefs from scientific evidence related to their chosen SSI, and helping students use scientific processes while constructing knowledge. Leung's (2021) study, found that prospective teachers initially held traditional views on science education such as content delivery as a primary focus. However, many of them shifted their beliefs at the end of the course to engage their students in real-world scientific issues with social implications, which fostered critical thinking and scientific literacy. Kinskey and Newton (2024) demonstrate that training pre-service teachers both in methods and content produces a better understanding of SSI and therefore serves to

develop more effective science instruction towards developing a citizenry capable of increased science literacy. It is evident that to be successful in incorporating SSI into the curriculum, teachers must feel confident in the PCK and participating in SSI-direct PD is an effective way to address this need.

SocioTransformative Constructivism

The controversial nature of SSI offers a unique opportunity for educators to teach STEM content in a way that addresses issues of power and social justice. This approach counters the traditional fact-oriented, culture-free view of STEM subjects and teaching. Such an approach requires the reconceptualizing of teachers' views of STEM instruction to integrate social justice pedagogy, and in doing so, many teachers exhibit resistance at the ideological level stemming from feelings of guilt, defensiveness, and shame when confronting social justice and oppressive norms like racism (Rodriguez, 2005). Pedagogical resistance is also common and involves the management of conflicting classroom expectations, such as administrative expectations, curricular fulfillment, and implementation of student-centered activities (Rodriguez & Berryman, 2002).

Rodriguez (1998) developed the sTc framework as a means to counter these resistances. The sTc framework is a powerful tool for addressing and understanding social justice in STEM classrooms and engaging teachers and students in empowering dialogues (Rodriguez & Berryman, 2002). Using a multicultural education and social constructivism, sTc acknowledges how issues of power, gender, and equity all influence curriculum and its delivery. sTc emphasizes the presentation of socially relevant knowledge to engage students in meaningful dialogue and active community participation (Rodriguez & Berryman, 2002). This also provides a powerful framework for understanding how and why students engage differently in specific content and how that engagement fosters student agency both inside and out of the classroom (Johnson et al., 2024).

The sTc framework consists of four elements: dialogic conversation, authentic activity, metacognition, and reflexivity (Rodriguez, 1998). Dialogic conversation encourages recognition of how individual voices create context relevant meaning, moving beyond understanding what is said to understanding the reasons behind saying it (Rodriguez & Berryman, 2002). Bakhtin (1986) described dialogue as essential to authentic human life: "to live means to participate in dialogue: to ask questions, to heed, to respond, to agree, and so forth" (p. 293). Jewitt et al. (2001) noted that traditional didactic instruction is often lacking this dialogue component.

Authentic activities involve students' exploration of a topic's social and cultural relevance connected to their own experiences (Rodriguez & Berryman, 2002). Such work is both complex and meaningful and involves the application of knowledge and skills beyond routine memorization (Newmann et al., 2001). When teachers base pedagogy on assignments requiring higher order thinking, in depth understanding, and connections to students' lives, students produce more complex intellectual work.

Metacognition was defined by Bransford and Donovan (2005) as monitoring one's understanding, and involves thinking about one's thinking and identifying deficiencies therein. Rodriguez (1998) adds that critical questions like "why am I learning this?" and "what control do I have in my learning" foster a higher level of consciousness and agency in the learning process.

Reflexivity involves exploring social, ideological, and academic locations concerning student and teacher perceptions of what may be worth learning (Rodriguez, 2005). This helps to address inequality by increasing understanding of positionality and acting on new knowledge to facilitate social change (Rodriguez & Berryman, 2002).

In this study, we utilize the sTc framework to connect social justice and SSI. The sTc framework offers a comprehensive approach to the incorporation of social justice in STEM education by emphasizing dialogic conversation, reflexivity, metacognition, and authentic learning experiences. By teaching with an sTc framework, learning becomes inquiry-based, hands-on, minds-on, socio-culturally relevant and

tied to the everyday life of the learner (Rodriguez, 2015). Similarly, teaching STEM with an sTc framework addresses the resistance teachers may face, while also promoting student agency and meaningful learning.

Student Agency

An important component to the sTc framework is the idea of student agency, a concept that is often at the forefront of discussion of 21st century learning skills and current educational policy. Agency has been defined as "intentional acts based on people's beliefs about their ability to control events" (Bandura, 1997). Rodriguez and Berryman (2002) defined agency as "the conscious role that we choose to play in helping to bring about change for the benefit of all and especially for the benefit of those who occupy disadvantaged positions in comparison with ours" (p. 1020). Moses et al. (2020) defined student agency as "students' capacity to act in ways that exhibit their own choices in their learning, informed by their beliefs and care consideration, self-regulation, self-reflection about their ability to control and take ownership of their own learning" (p. 214). Teaching with an SSI/sTc framework provides opportunities for purposeful and intentional practices aimed to instigate students to take control of their learning and increase their ability to effect change, all within the context of a STEM classroom.

Student engagement and agency increase when students are given the opportunity to drive their own learning within the context of an SSI (Johnson et al., 2024). Ke et al. (2020) highlighted the value of understanding how students see their education, and shows that if a student understands how to approach issues with epistemic tools or system thinking, they develop a higher level of agency. Morales-Doyle (2017) found that engaging students in a social justice oriented SSI (SJSI) enabled students to position themselves as "transformative intellectuals" with nuanced thinking in science and justice-oriented contexts. Students need more guidance in order to connect with content at this deeper level; they need to be presented with scaffolds to achieve the autonomy required to reach this increased science learning. This requires active participation in civic and scientific decision-making in society (Lombardi et al., 2022). In order to reach increased engagement and agency, the teachers must first transition from "knowledge transmitters" to facilitators that redistribute power to the students.

Karahan and Roehrig (2017) found that when teachers shifted their role from content provider to content facilitator, the classroom environment fostered student agency, empowerment, and ownership in accepting proactive roles in addressing environmental issues. In addition to shifting the learning to students, grounding STEM content within a local issue proves to support student agency. Karahan and Roehrig (2016) discussed how a focus on local environmental issues facilitated student agency, promoted intrinsic motivation to connect with the content, while at the same time addressing complex, real-world issues. With this active participation in decision-making in SSI based content, students showed an increase in agency in science. These case studies show that applications of SSI can promote student agency and engagement, and while developing these pedagogies has been adequately researched, further research should be dedicated to understanding how to connect these pedagogies to professional development. Johnson et al. (2020) found that teachers may lack confidence in teaching with the SSI framework, yet SSI focused PD can be effective at developing the skills and knowledge to successfully implement SSI into STEM classrooms. It is for these reasons that the current study explored the impact of SSI integration in participant teachers' classrooms on their students' agency.

RESEARCH METHODS

The goal of this qualitative case study was to explore how teachers participating in a SSI focused PD use an SSI/sTc framework as an avenue to empower their students to become agents of change outside the classroom and develop agency in their learning. Case study research involves a bounded "case" or "cases" within clearly defined, real life contexts (Creswell & Poth, 2016). This research methodology allows researchers to delve deeply into complex aspects of the selected case (Johnson & Christensen,

2019). For our study, we are highlighting four teachers who demonstrated effective strategies for encouraging student agency within an SSI unit. We sought to answer the following research question: in what ways, if any, do participant teachers foster authentic, active engagement and student agency in their STEM classroom following participation in an SSI focused professional development program?

Professional Development

The four case study teachers in this study applied for and were selected to participate in a two-year SSI focused PD program. The teachers' demographic backgrounds varied (see Table 1), yet all were interested in increasing their knowledge of SSI and social justice and in changing their instructional strategies to more effectively meet their students' needs. The PD was localized in a large urban area in the northeastern United States and was approved by the ethics committee of the primary institution in November 2021. The purpose of the PD program was to ground SSI within the context of STEM lessons, provide teachers with an extensive professional network, and to build deeper SSI pedagogical and content knowledge through intensive workshops and PD sessions (see Appendix 1). Four of the twenty three teachers participating in the PD program were selected as case study teachers. They were selected based on review of their SSI units of study to represent effective strategies for fostering student agency through their SSI units.

Over the course of their participation in the PD, teachers designed and implemented sets of SSI focused lesson plans referred to as a unit of study. Teachers selected their SSI unit topics based on their curriculum, which was taught during the spring semester. To integrate SSI into their STEM content, teachers were introduced to a framework addressing SSI with an sTc focus (see Appendix 2). The framework consists of four domains: social, scientific, discursive, and justice. The social domain addresses the societal aspects of an issue focusing on issues of relevance and interest to the students, as well as, the various systems and perspectives of the issue. The scientific domain explores the scientific phenomenon or concepts in mathematics associated with the SSI and encourages students to actively engage with the science or math content. The discursive domain promotes the use of activities that allow students to think logically and analytically, critique or be skeptical of information, use data to explain their position, the strengths and weaknesses of their claims or identify their biases or limitations connected to their SSI, and reflect upon their role in influencing themselves and/or others with regard to the SSI. The justice domain prompts students to elicit and voice their perspective, to acknowledge how privilege may play a role in resolving the SSI, to engage in inquiry-based learning activities tied to their everyday life, to co-construct knowledge to develop understanding and to reflect on their learning experiences to improve learning and gain more ownership over their learning.

Table 1.
Teacher Participant Information

Teacher pseudonym	Years of Teaching experience	Grade(s) taught	Subject Taught	SSI Unit Topic
Ms. Perez	29	8-12	Environmental Science	Biodiversity and Land Use
Mr. Harris	11	9-12	Physics	School Zone Speed Limits
Ms. Walker	26	Combined 7th/8th	Gifted STEM/ELA	AI use in schools
Ms. Scott	35	9-12	Eco-Schools	Biodiversity and Land Use

Data Collection

Data utilized for this case study included a finalized unit of study, teacher selected student artifacts, an end of the year interview, and a written end of the year reflection. At the end of their second year in the project, the case study teachers submitted a finalized unit of study. The teachers had an opportunity to implement their unit of study at least twice during their time in the PD and as such, revised and updated the unit as necessary before submitting their finalized unit. Teachers also submitted student artifacts

such as assignments, projects, essays, videos, or posters demonstrating the students' learning of SSI, their stance on social justice, and any challenging components of SSI. Teachers participated in an end of year interview in which they answered open-ended questions about their knowledge and teaching practices for integrating social justice and student agency into their STEM teaching (see Appendix 3). Finally, the teachers submitted an end of the year reflection in which they described a lesson they taught that exemplified ideal STEM instruction, recounted in what ways, if any, they engaged and motivated their students to learn STEM with a focus on debatable issues and/or real-word problems, described how they incorporated social justice into their teaching, and documented any challenges they encountered during the implementation of their unit.

Data Analysis

To understand the ways in which teachers promoted student agency within their SSI units of study, we applied Braun and Clarke's (2006) thematic analysis to identify, analyze, and interpret the data. Inductive analysis was utilized to develop codes from the data related to teacher practices connected to fostering student opportunities to authentically effect change within their school communities. Three researchers analyzed the finalized units of study, student artifacts, end of the year interviews, and end of the year reflections for examples of teachers encouraging student agency. To develop a preliminary interpretation of the data, the researchers read through all the data more than once. Interesting or meaningful keywords and phrases related to student agency were identified and discussed. Any words or phrases that appeared more than once were noted to help with the theme development. After this initial coding, the researchers viewed the data as a whole, looking for relationships between codes and working to combine them into themes. Throughout this process, the researchers revisited the data to ensure they were accurately capturing each instance in which students had the ability to affect change. A coding guide was developed and revised through discussion amongst the researchers, evolving from a simple interpretation of the data to one of depth, which genuinely reflects the ways in which teachers promoted student agency within their classrooms (see Table 2).

Credibility, reliability, and trustworthiness was established through triangulation of our data (Denzin, 2009) and through ongoing discussions amongst the researchers. Given the exploratory nature of the study, we developed emergent themes from the data to capture the breadth of teachers' experiences designing and implementing these units with promoted student agency.

RESEARCH FINDINGS

The selected SSI employed in the units developed by our case study teachers included designing plans for a school courtyard, drafting a school artificial intelligence (AI) policy, and writing letters to state representatives. Below is an overview of the experiences outlined for the separate units followed by an exploration of dominant emergent themes related to the promotion of student agency within their SSI units.

Student Agency in Action

Mr. Harris

Mr. Harris opened his unit with a recent local news segment on two pedestrians hit by a car near a local high school to provide context for the unit. He reasoned that the local news segment created cognitive dissonance among his students since many students believe that grownups and high school students do not need special conditions to safely cross the street ie. school zone, crosswalks, pedestrian crossing signs, etc. Secondly, it provided relevance for his students who can identify with the experience of crossing a street to/from school and are familiar with the local school involved in the story. Lastly, the context provides several contrasts that the teacher uses to introduce multiple perspectives and

perspective-taking: a) the people interviewed in the story do not look like the students in his classroom; b) the homes shown do not represent the homes of his students (multifamily vs. single-family homes); c) the area surrounding the school district is urban vs. rural; and d) there is a stark difference in population density surrounding each school.

To become more aware of the issue with school safety zones, the students read articles about the relationship between speed and safety and the difficulty with establishing a statewide law about speeding in school zones. The students conducted labs to gain hands-on experience with one dimensional kinematics concepts including speed, motion, acceleration, and velocity. During one lesson, a local police officer was invited into the classroom to have a discussion and question/answer session regarding speed limit monitoring and enforcement. In another lesson, students went outside on their school grounds to measure speed data directly for further analysis. Students created models of their school zone and the behaviors of drivers when the school zone is active and inactive.

After gathering information and engaging in hands-on learning, the culminating activity asked students to take a stance on whether the school speed zone is adequate. They researched their local state representative and wrote letters advocating for their position on school zone speed limits. The students' letters were sent to their local state representatives and many students received responses which they brought to school to share with Mr. Harris and fellow classmates.

Ms. Perez and Ms. Scott

Ms. Perez and Ms. Scott created a unit of study together focused on lawns and biodiversity. They each implemented the unit in their individual classrooms, yet often discussed and collaboratively revised the unit throughout the implementation. The unit of study opened with students considering lawns and if they are "good" for the environment, as well as what is required to maintain them. To increase their awareness of the issue related to lawns and biodiversity, the students viewed pictures of lawns and answered questions about which lawn is more appealing, in which type of lawn would they like to spend time; which type of lawn requires more time or money to maintain; which lawn represents a healthier ecosystem; which lawn is more diverse; what can live in a lawn; and if it is important for them to have a nice yard or lawn. This exercise allowed the teachers to gain background knowledge on students' impressions and thoughts about lawns. To gain a more holistic view of lawns, the students engaged in an implosion activity, adapted from Dumit (2014), and studied the labor, professional/epistemological, material, context, political, economic, textual, bodily, historical, and mythological dimensions of the issue.

The students conducted research related to the ecosystem outside their school and learned the realities of a manicured lawn. Realizing that many organisms are missing in the school ecosystem, students researched a native plant to determine the benefits of the plant to the school ecosystem and created an advertisement elucidating strengths and contributions of the native plant. As a culminating activity, the students used their knowledge to draft designs for the courtyard space, incorporating native plants and considering appropriate school uses. The final design included a scale plan of the courtyard, a list of native plants, a plan for the built components of the courtyard including benches or tables, a preliminary grant application to fund the project, a presentation seeking support or permission from the school board, town environmental advisory committee, and the local education foundation, and a documentary website or video of the thought process behind the study and design of the courtyard, which was to be presented to the school board.

Ms. Walker

Ms. Walker developed a unit of study focused on Artificial Intelligence (AI) use in schools. She recognized that her students were unaware of the many uses of AI, its presence in their lives, and the benefits and challenges of the technology so she offered many activities to increase the students' knowledge of AI. She began by having students reflect on their personal attitudes and beliefs regarding

existing rules to develop an understanding of the necessity for rules. They discussed the importance of rules or policies within the school. Since many students have cell phones, they looked specifically at the school's policy related to cell phone use. The students then began to research AI and considered the benefits and drawbacks of this technology in the following categories: equity & accessibility, privacy & data security, teacher & student roles, loss of human connection & social skills development, ethical decision making & accountability, teacher professional development, human creativity & critical thinking, job displacement & workforce preparation, and transparency & explainability.

The students read articles and watched videos about AI use and had an opportunity to practice with different AI tools, platforms and applications. Students interviewed and surveyed different stakeholders including their peers, teachers and parents and found diversity in thoughts and opinions, which demonstrates the highly debatable nature of the SSI topic.

After gathering all the information needed, groups of students drafted a school/district AI policy that positively supported the students' learning and development. The students revised their policy to incorporate the perspectives of the multiple stakeholders who were invited to review the proposals. While the students' policy was ultimately not adopted, Ms. Walker found that her unit gave students more opportunity to express their opinions in their own voices in ways that can result in changes in their community.

Teachers' Strategies for Promoting Student Agency

The way in which teachers encouraged student agency in their units of study varied, yet commonalities were evident and woven into three themes: moving beyond traditional STEM content, moving beyond the classroom walls, and moving inward (see Table 2). The table also includes a composite description for each theme used to understand how teachers promoted student agency. The sub-themes are not necessarily distinct in application; activities from the teachers' units of study can and often did fit into multiple categories. We discuss them separately, yet examples can overlap as each describes a critical factor in promoting student agency.

Table 2.
Final Themes and Composite Descriptions

Themes	Sub-themes	Descriptions
Moving beyond traditional STEM content	Cross-curricular	Extending beyond the traditional, culture-free view of STEM content; developing knowledge, skills, and understanding of interconnected topics
	Collaborative	Working with teachers outside of the core content area; learning from community experts
	Multiple-perspective taking	Exploring and incorporating the perspectives of a range of stakeholders
Moving beyond the classroom walls	Applicable life skills	Developing and applying skills that will be useful throughout life; providing opportunities for interactions with others outside of social circle.
	Content and real world connection	Making tangible connections between content taught and lived experience
	Extension activities and applications	Directly interacting with and impacting issues outside of the classroom; taking action and applying new knowledge
Moving inward	Immediate school focus	Pinpointing a highly relevant issue to the school community
	Student engagement and acceptance	Seeing a purpose; believing they can make a difference; taking concrete steps toward action
	Authenticity	Feeling relevant and connected to the students' lives; innately engaging and or accessible

Moving Beyond Traditional STEM Content

Each of the case study teachers made it a priority to extend learning beyond the traditional STEM content. They framed the learning of the STEM content within a relevant and local SSI. They provided opportunities for students to explore and explain the scientific phenomenon through active learning and considering the systems associated with the SSI and STEM content. The learning engaged students in cross-curricular and collaborative activities that promoted multiple-perspective taking.

Cross-Curricular

For the teachers in this study, cross-curricular content was vital. They incorporated the perspectives of non-science/STEM stakeholders and encouraged students to connect these viewpoints to underlying science conceptions and misconceptions, thus developing functional scientific literacy. These efforts extended learning beyond the traditional, culture-free view of STEM content and developed knowledge, skills, and understanding of interconnected topics. For example, beyond a study of biodiversity and ecosystems, Ms. Perez and Ms. Scott taught students to evaluate the economic impacts of lawns, and had students consider other factors including mental health, violence prevention, food deserts, home values, and laws and regulations. Mr. Harris taught his physics students one-dimensional motion, but also incorporated civics into the evaluation of local speed zones. Mr. Harris noted a key takeaway for his students was that real-world scenarios are messy and that to "make informed decisions about real questions we need knowledge from many different sources and content areas." Similarly, while Ms. Walker's students learned about AI technology, they also considered the moral aspects of it and the philosophical purpose of rules within a society, ultimately leading to students to developing a school policy on AI usage.

Collaborative

The case study teachers prioritized collaboration with educators outside of the core content area. Collaboration occurred in the designing of the unit, in co-teaching, and through learning from community experts. Ms. Perez and Ms. Scott, who both teach science across multiple grades, collaborated with each other to create and revise their unit of study. Ms. Perez highlighted the importance of collaboration when she stated that a benefit of her experience in the PD program was that she had colleagues from her school participating with her, and that they "could help each other and support each other … [and] have the ability to bounce things off each other". Ms. Walker developed and delivered her unit on AI in schools with the English Language Arts (ELA) gifted teacher. Mr. Harris consulted with his colleagues in the social studies department and discovered that civics is not explicitly covered in the curriculum, making him feel that it was necessary to cover civics within his physics class. He also collaborated with a law enforcement officer who discussed speed zones with the students.

Promoted Multiple-Perspective Taking

Included in each of the units of study were opportunities for students to obtain, explore, compare, or contrast perspectives from a range of stakeholders. As an example, Ms. Walker had her students conduct stakeholder interviews with parents, teachers, administrators, and other students about AI tools for learning and the potential for an AI school policy. The students analyzed data they collected to better understand the varied perspectives and ultimately incorporated them into their school policy to ensure that all perspectives were represented. Mr. Harris introduced his unit with a news story about an automobile accident which occurred in a nearby urban school zone. He specifically chose the context of an urban school zone to contrast the rural district in which his students attend. He wanted his students to consider the perspectives of people of different socioeconomic and cultural backgrounds than their own. Ms. Perez and Ms. Scott both teach in a suburban school district in which their students regularly see manicured lawns. To understand the complexities of the manicured lawn, the students investigated the various systems associated with creating and maintaining lawns as well as the perspectives of multiple stakeholders such as the professionals who care for lawns, the politicians who create the

regulations associated with lawns, those who market and those who use lawns. In each case, the teachers provided opportunities for their students to expand their knowledge by exploring the perspectives of multiple stakeholders.

Moving Beyond the Classroom Walls

The case study teachers designed and implemented units of study that encouraged learning outside of the classroom. Developing and strengthening life skills was prominent in each unit of study. Likewise, teachers made tangible connections between the content and the real-world. Finally, all the units included extension activities that spanned multiple topics over numerous lessons and days.

Applicable Life Skills

Each of the case study teachers described how they wanted their students to learn more than the content; they intended for their students to gain valuable knowledge and develop and apply skills that would be useful throughout life. For example, Mr. Harris wrote about his decision to include advocating their position on school speed zones to their local state representative,

> *The rationale for this type of structured action is rooted in the educational philosophy that students are citizens and their schooling should prepare them for their civic duties. Parallel to that thinking is providing students with the tools to access a voice in their communities. Empowering students to formulate and advocate opinions on issues within their community allows them to access power to make change and exercise their background (cultural, moral, socioeconomic, etc.). Depending on the issue, the vehicle by which students advocate for issues in their communities is a democratic framework - albeit more directly at local and municipal levels than at state and national levels where citizens advocate through representatives.*

Mr. Harris recognized the interconnectedness of schooling, specifically the lesson he was teaching, and the essential skills his students would need in their futures.

To increase her students' comfort level with speaking in front of others, Ms. Walker provided numerous opportunities for her students to voice their opinions and share their knowledge. Similarly, she thought it was important for her students to increase their comfort level with speaking with people outside of their social circle and thus, had her students conduct surveys and interviews with the various stakeholders. Mr. Perez described how she wanted her students to become more aware of the world around them. She stated, "We live in a pretty affluent district so not all of the students are aware of… what other people might be experiencing. So to make them more aware of things that are not fair in the world, I think is a valuable lesson for them. And I don't know that they're learning that anyplace else." Ms. Scott incorporated citizen science into her teaching so that her students would know that

> *all the science that we do contributes somewhere to the planet, to technology, development, to other people. That it's just something that… we're not studying rocks and minerals because they're pretty…we study them because we use them for things, or you can find these minerals in your houses. And this is what your buildings are made up of. And so there's always something that ties into your life, even if you don't see it at the moment.*

As with Mr. Harris, Ms. Scott recognized that the content taught is directly applicable to students' lives and that that knowledge will be useful to them in their lives beyond school.

As evidenced in the examples above, learning valuable life skills and lessons was just as important as learning the STEM content for the teachers in this study. Whether it was becoming civically engaged, building confidence with speaking in front of and with others, becoming aware of the larger world around them, or knowing that science done in the classroom matters, the students all gained skills which will benefit them throughout their lives.

Content and the Real World Connection

In line with the applicable life skills described above, it was a priority for the case study teachers to make tangible connections between content taught in the classroom and the lived experience of the students outside of the classroom. For example, Ms. Walker had her students research AI tools that can be used to complete school work, while Mr. Harris began his unit with a news segment regarding an instance of two pedestrians being struck by a vehicle in a nearby school zone. Ms. Perez and Ms. Scott's students investigated the biodiversity within their school lawn using the iNaturalist app and quantified the organisms living within the soil. They also learned about native species, their needs and how they fit into the ecosystem, and whether or not their needs can be met on the school grounds.

Connecting STEM content to students' lived experience provided avenues for students to leverage the knowledge that they bring with them, validating their knowledge and cultural perspective while engaging them in STEM learning. For example, Ms. Perez explained in her end of year interview how she had two students in her class from Ukraine, who were able to provide a different cultural lens to the topic as they did not grow up with grass lawns and did not understand its importance to Americans. Mr. Harris also welcomed students' previous knowledge and experience into his classroom. He explains

> *Students come into the classroom with a variety of prior conceptions, experiences, opinions, and knowledge. I want students to share these aspects of their lives with their peers in an environment where we can gather authentic information concerning this issue. It's important that students take information gathered from their peers and use it to process their own thoughts and feelings on the issue. This reflexivity can be summed up with a quote from one of my students, 'Mr. [Harris], I know from all of the physics and the reading and the statistics that a 15 mph school zone is probably the most safe for pedestrians, but I still want it to be higher. I mean, I have places to be!'*

Mr. Harris supported his students in their development of understanding of the content as they connected the knowledge that they brought with them to class to the new content knowledge they gained from their SSI lessons. This practice validated his students' perspectives, giving them space and agency to express their opinions while pushing them to support their claims and expand their understandings.

Extension Activities/Application of What Has Been Learned

The case study teachers intentionally extended learning outside of the classroom by facilitating active community engagement. By working collaboratively with groups in the local community, students were afforded the opportunity to apply what they were learning and effect change. For example, Ms. Perez and Ms. Scott offered extension activities following implementation of their units in which students volunteered in the school garden growing vegetables to donate to the local food pantry. This act directly applied what they learned about local ecosystems for the benefit of the larger community. The students also investigated water quality in their local watershed and discovered the cleaning of their school stadium contributed to pollution in a nearby creek. The students connected with local stakeholders to contribute to the community discourse about the issue. Mr. Harris' students contacted their local state representatives to write letters advocating the students' position on school zone speed limits. As Mr. Harris stated, "Empowering students to formulate and advocate opinions on issues within their community allows them to access power to make change and exercise their background (cultural, moral, socioeconomic, etc.)..." Ms. Walker had groups of students draft proposals for a school or district-wide AI policy that positively support students' learning and or development. Multiple stakeholders (students, teachers, parents, and administration) shared their perspectives with the students and as a result, the AI policies were revised to integrate stakeholder feedback.

In each case, teachers fostered student agency by allowing students to directly interact with and impact issues relevant to their lives, yet also of importance outside of the classroom. This intention allowed for a shifting of the lesson dynamic to a more student-driven focus. The students had the ability to apply their newly attained knowledge and effect change.

Moving Inward

While teaching with an SSI focus allows for teachers to ground STEM content in a real and relevant topic, the topic may oftentimes be less directly impactful to the students' immediate environment and lives. This was not the case for the case study teachers who each chose a highly impactful SSI that had direct relevance to the lives of the students and the school community. While SSI can encompass larger, broader issues, the case study teachers' choice to focus on more locally founded issues resulted in student engagement, acceptance, and a truly authentic learning experience.

Immediate School Focus

Each case study teacher considered the students' interests and recognized a need within the school. This allowed for students to conduct research and develop a plan of action to address an issue that directly impacted their schools. For example, Ms. Perez and Ms. Scott highlighted that the "largest contiguous "lawn" in the borough is [their] school district's grounds. They wanted their students to know what impact the grassy areas around the school can have on the world around them as well as what alternatives are available. Regarding the use of AI in schools, Ms. Walker noted "no policy currently exists in most schools, and likely none to be written in the near future." Recognizing this need and the relevance of the issue to the students' lives, Ms. Walker tasked her students with creating an AI policy for the school. Similarly, Mr. Harris pinpointed an issue personally affecting his high school – the speed limit in the school zone. He stated "high school students drive or are driven, on a variety of roads at a variety of speeds, but they all experience traveling through a school zone in their daily pilgrimage to and from school," He challenged his students to determine if their school zone speed limit is adequate and if not, to take action toward addressing this issue by writing to the state representative. In each case, students actively learned about and addressed an issue of significant concern to themselves and their school.

Student Engagement and Acceptance

For the case study teachers, it was vitally important for the students to connect with the SSI. They needed the students to see a purpose in the learning, believe they could make a difference, and then take concrete steps toward action. Ms. Walker noted that there is not a policy regarding the use of AI in her school or district. After investigating the technology and conducting stakeholder interviews, students were asked "Why is a clear student use policy/rule important for our community?" By asking this before students began to develop their draft of a policy, students were engaged in the purpose of their work and understood the call to action. Ms. Scott and Ms. Perez noted that their school community "prides itself on its suburban identity. Children play in yards; residents walk to friends' houses, shops, restaurants, public transportation, and school; and enjoy free and open access to the only open space in the borough on School District property. There is a growing population of students living in rental units without access to private outdoor space." Before students designed their courtyard solutions, they first investigated the importance of biodiversity, native plants, alternatives to traditional lawns, and green spaces, so that when the students exercised their agency, they saw the purpose of the work and were engaged in making a difference.

Authenticity

Teachers strived to make the SSI unit of study authentic and relevant to the lives of their students. The students engaged in hands-on, inquiry-based, and culturally-relevant activities that promoted feelings of relevancy and connection. Class activities were reflective of scientific practice of STEM professionals as students applied their learning to address real and pertinent issues. Ms. Perez and Ms. Scott's students conducted research related to the ecosystem outside their school using scientific equipment to gather and interpret real data in learning how lawncare impacts the larger local ecosystem. Similarly, Ms. Walker's students interviewed and surveyed different stakeholders regarding AI and analyzed their results. Data in each case was student generated and analysis was student driven, shifting the power dynamic to a more student-centered classroom and engaging the students directly in the scientific

process. Ms. Perez and Ms. Scott had students create scale plans for the courtyard design including lists of native plants and built components like benches and tables. Beyond the plans, the students developed grant applications to fund the project and presentations seeking support from the school board, educational foundation and township environmental advisory committee. For the students in Mr. Harris's class, they had the ability to effect change that benefited not only the students in their school, but the local community as well. After researching and learning about speed, motion, and acceleration, they debated whether the speed in the school zone was adequate and then contacted their state representatives to share what they learned and to advocate for their position on school zone speed limits.

These activities, which go beyond traditional STEM content, are examples of hands-on authentic learning experiences and demonstrate that learning STEM content with a student agency lens was innately engaging and made the topics accessible to the students.

CONCLUSION AND DISCUSSION

In this study, we investigated the experiences and practices of four STEM teachers who promoted student agency to address an SSI. One research question guided this study: in what ways, if any, do participant teachers foster authentic, active engagement and student agency in their STEM classroom following participation in an SSI focused professional development program? Findings indicate that teachers were successful in providing students with authentic learning opportunities in which students developed agency through their SSI units. Specifically, students developed a sense of agency by engaging in activities that were cross-curricular and collaborative and promoted multiple-perspective taking; that cultivated and strengthened life skills, made tangible connections between STEM content and the real-world and extended student thinking beyond the classroom; and that had authentic and direct relevance to the school community, resulting in student engagement and acceptance. The SSI topics investigated in the case study teachers' units of study, allowed students to become agents of change and apply what they were learning to address local issues, meeting the need to make STEM learning authentic and relevant to their lives (Zeidler, 2014).

The case study teachers embraced the idea of engaging their students in real, hands-on learning experiences outside of the classroom which fostered a sense of agency and encouraged students to apply what they were learning to issues facing their schools. Whether it was creating an AI policy for school, redesigning a school courtyard, or writing local representatives to address the school zone speed limits, students saw an authentic purpose and took steps to address the issue. The study conducted by Ke et al. (2020) demonstrated that students' perceptions of SSI approaches depend on topics being relevant, interesting, supporting their agency, and beneficial for learning. Our study extends these findings by highlighting the common characteristics which support student agency within different SSI units of study. Karahan and Roehrig (2016) had similar results when students focused on a local environmental issue for which they were passionate. The highly localized focus of the case study SSIs promoted intrinsic motivation to connect with the content, while still addressing complex, real-world issues. Similarly, Morales-Doyle (2017) found that students were capable of being transformative intellectuals when engaged in the complexities of science and social justice with a commitment to their local community.

The PD at the focus of this study utilized an SSI/sTc framework as a method for enabling teachers to shift their teaching practices to be more authentic and student-focused, in essence enabling students to make change. All four case study teachers described how their knowledge and teaching practices for implementing SSI in the classroom changed as a result of their participation, which supports previous research highlighting the benefits of SSI focused PD (Johnson et al., 2020). Throughout the two years of the PD, the teachers had numerous opportunities to develop their own sense of agency by sharing feedback, offering suggestions, and helping with the planning and content of the PD. Robertson et. al. (2020) found that teachers who participated in a PD that fostered teacher agency may also promote

student agency. Hence, when teachers feel empowered to teach content in a way that best serves their students, students feel vested to take control of their learning and effect change.

By providing teachers with a SSI/sTc framework that encourages students to employ reflective skepticism, elucidate their own opinions and solutions, and practice reflexivity, dialogic conversations, and metacognition, as well as through the intentional empowerment of teachers during the PD, teachers were successful in supporting student agency in their classrooms. The study highlights the importance of providing teachers with PD to support their endeavors to make STEM content authentic and relevant to the students' lives.

Limitations of Study

For this study, we applied a qualitative case study methodology and as such, our case was limited to STEM teachers who volunteered to participate in an SSI focused PD. Hence, because of the selected methodology, we are unable to generalize the findings to PD geared toward other disciplines. Additionally, our participants are geographically concentrated and self-selected to participate in our PD program, which also affects the generalizability of our findings. While our study was limited to in-service teachers participating in a SSI focused PD, previous research suggests that pre-service teachers also benefit from engaging in SSI focused coursework (Johnson, et al., 2020; Kinskey & Zeidler, 2024). Our data was limited to teacher-focused unit plans and reflections and may not fully represent the students' experiences in SSI and student agency. While our findings are promising, future research endeavors can include: a) an evaluation of the PD to determine which components best supported the application of student agency into an SSI unit; b) investigating how teachers promoted student agency outside of the school community; and c) a longitudinal study to determine if partnerships within and outside the schools created during the unit implementation continued after participation in the PD.

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APPENDICES

Appendix 1: Professional Development Activities

Activity	Year 1 (2021-2022)	Year 2 (2022-2023)
Learning Institute	Tuesday Evenings, August - May 3 hours each Supporting Student Engagement Modification of Units Microteaching	August 9 days, 6 hours each Supporting student engagement Modification of Units Service Learning Teacher Leadership Competencies
Professional Learning Community	January - May 6 sessions; 3 hours each Refinement of SSI/ sTc Dimensions, Reflection of Practice, Coaching Session	January - May 6 sessions; 3 hours each Refinement of SSI/ sTc Dimensions, Reflection of Practice
Workshops/ Field Trips	August - May 3 days; 6 hour each Ethics and SSI in Classroom Sustainability Ideas into Math Courses Mural Arts Philadelphia	August - May 3 days; 6 hours; Teacher Leadership Development Stakeholder Engagement Community Partnership African American Museum
Classroom Support Visits	January - June 2 visits per teacher Implementation of SSI Lessons, Lesson Consultation and Reflection	NA
End-of-Year Conference	May 1 day; 6 hours; Leadership Keynote Speaker, SSI Workshops, Presentation on Mini Units of Study	May 1 day; 6 hours; Keynote Speaker, SSI Workshops, Table Talks-Units of Study

Appendix 2: SSI/sTc Rubric

Domain 1: Social Aspects
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 (Paige, & Hardy, 2014; Zeidler & Kahn, 2014).
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.
Domain 2: Scientific Aspects
4) Explore and explain the underlying scientific phenomena and/or concepts in mathematics Think of opportunities for students to explore and explain the scientific phenomenon or concepts in mathematics associated with the focal issue. This anchor phenomenon must be relevant to students' everyday experiences, observable, complex, have associated data, text and images, and part of the school's curriculum (Penuel & Bell, 2016).
5) Engage in STEM modeling Allow students to engage in scientific modeling and reasoning through development, use, evaluation, and revision of STEM models that are connected to the SSI discussion. Models are used to convey and explain information through investigations. Example classroom models include: conceptual (e.g. drawings and sketches), mathematical (e.g. graphs and equations), physical (e.g. stream table), engineering (e.g. designs and physical model of a bridge), and computer-oriented model (e.g. online simulation) (Macalalag, 2012).
Domain 3: Discursive Aspects
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.
Domain 4: Justice (sTc) Aspects
8) Reflexivity Providing avenues to elicit and voice with respect 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 (Calabrese, 2003; Rodriguez & Morrison, 2019; Zeidler, 2016).
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.

Unit Planning Rubric/Guide

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 & Kahn, 2014, p. 31).		
Level 3	**Level 2**	**Level 1**
The purpose of learning is framed by a problem or question of social significance (for the purpose of informed and responsible decision-making) beyond science and mathematics. The unit contains one overarching SSI that includes moral and ethical decision making.	The purpose of learning is framed by a problem or question of social significance (for the purpose of adding different real-world connections) beyond science and mathematics. The unit contains multiple or disconnected SSI.	The purpose of learning is framed in learning content knowledge and skills in science and mathematics.

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. If considering or analyzing system dynamics are not present, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**
The plan includes an Embedded SSI that is situated within the larger social systems (e.g., political, economic, ethical, religious). Clear and explicit connections are made between STEM topics and related systems.	The plan includes clear connections that are made between STEM topics and related social systems, but these connections are not thoroughly explored by students within the context of the lesson.	The plan includes discussion of system dynamics (e.g. political, economic, ethical, and religious) that are not connected to the SSI discussion or connections between STEM topics and related systems are implicit or unclear.

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. If comparing and contrasting multiple perspectives is not present or not connected to the SSI, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**
The plan includes instructional strategies for students to obtain, explore, compare, or contrast perspectives from a range of stakeholders (e.g. environmental activists, politicians, political groups) that are connected to their SSI discussion.	The plan includes instructional strategies for students to obtain, explore, compare, or contrast perspectives from a select few (one or two) stakeholders (e.g. environmental activists, politicians, political groups) that are connected to their SSI discussion.	The plan did not provide scaffolding for students to obtain, explore, compare, or contrast perspectives from a range of stakeholders (e.g. environmental activists, politicians, political groups).

4a) Knowledge: Explore and explain the underlying scientific phenomena and/or concepts in mathematics

Think of opportunities for students to explore and explain the scientific phenomenon or concepts in mathematics associated with the focal issue. This anchor phenomenon must be relevant to students' everyday experiences, observable, complex, have associated data, text and images, and part of the school's curriculum (Sadler et al., 2019). If the anchor phenomenon is not present, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**
The plan includes students exploring and explaining the scientific phenomenon or concepts in mathematics that is part of the school's curriculum and is associated with the SSI.	The plan includes students exploring and explaining the scientific phenomenon or concepts in mathematics, but it is not associated with the SSI.	The scientific phenomenon or concepts in mathematics is unclear.
4b) PCK: Instructional Strategies on exploration of SSI Includes teachers' conceptualization and plan on how to engage their students in learning of scientific phenomena or concepts in mathematics. Active learning requires thinking and active participation of students in their learning process of SSI. If PCK is not present or unclear, then this component is scored as a zero.		
Level 3	**Level 2**	**Level 1**
The plan includes the teacher engaging students through active learning of scientific phenomena or concepts in mathematics that are connected to SSI.	The teacher engages students in activities that do not develop students' knowledge of scientific phenomena or concepts in mathematics.	The teacher engages students in passive learning (e.g. lecture) of scientific phenomena or concepts in mathematics that are connected to SSI.
5) Engage with STEM models Allow students to engage in scientific modeling and reasoning through development, use, evaluation, and revision of STEM models that are connected to the SSI discussion. Models are used to convey and explain information through investigations. Example classroom models include: conceptual (e.g. drawings and sketches), mathematical (e.g. graphs and equations), physical (e.g. stream table), engineering (e.g. designs and physical model of a bridge), and computer-oriented model (e.g. online simulation) (Macalalag, 2012). If STEM models are not present, then this component is scored as a zero.		
Level 3	**Level 2**	**Level 1**
The plan includes teachers asking students to develop, test, and/or revise models (e.g. conceptual, mathematical, physical, engineering, computer-based) based on students' investigation(s) embedded in the lesson that are connected to the SSI discussion.	The plan includes teachers asking students to use models (e.g. conceptual, mathematical, physical, engineering, computer-based) as a tool for conveying information that are connected to the SSI discussion.	The plan includes teachers asking students to use models (e.g. conceptual, mathematical, physical, engineering, computer-based) as a tool for conveying information, but the models are not connected to the SSI discussion.

<table>
<tr><td colspan="3">6) Employ reflective scientific skepticism

Teach students to consider the following questions while reviewing their data and sources of information (Sadler et al., 2019). If employing reflective scientific skepticism is not present, then this component is scored as a zero.</td></tr>
<tr><td>Level 3</td><td>Level 2</td><td>Level 1</td></tr>
<tr><td>The plan includes instructional strategies for students to analyze, critique, or be skeptical of any information that is connected to their SSI discussion. The analysis could include one or more of the following: (a) person/group/authors

(b) methodology/procedure

(c) Analysis of results

(d) interpretations/conclusions/ implications</td><td>The plan references critique/being skeptical, but does not engage/scaffold student ability to critique and be skeptical for students to analyze, critique, or be skeptical of any information that is connected to their SSI discussion.</td><td>The plan did not provide any focus/attention to analyze, critique, or be skeptical of any information that is connected to their SSI discussion.</td></tr>
<tr><td colspan="3">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. If elucidating one's own position/solution is not present or not connected to the SSI, then this component is scored as a zero.</td></tr>
<tr><td>Level 3</td><td>Level 2</td><td>Level 1</td></tr>
<tr><td>The plan includes instructional strategies for students to use data to explain their position, the strengths and weaknesses of their claims, or identify their biases or limitations that are connected to their SSI discussion. It also includes discussions of their role in influencing themselves and/or others with regards to the SSI discussion (agency).</td><td>The plan includes instructional strategies for students to present their position, but students are not required or instructed to use data to support their position, or to evaluate the strengths and weaknesses of their claims, or identify their biases or limitations that are connected to their SSI discussion.</td><td>The plan did not provide scaffolding for students to use data to explain their position, the strengths and weaknesses of their claims, or identify their biases or limitations that are connected to their SSI discussion.</td></tr>
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Sociotransformative constructivism (sTc)

8) Reflexivity

Providing avenues to elicit and voice with respect 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 (Calabrese, 2003; Rodriguez, A.J. & Morrison, D., 2019; Zeidler, 2016). If reflexivity is not present or not connected to the SSI, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**
The plan includes teachers prompting 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.	The plan includes teachers prompting students to elicit and voice their perspective on the SSI.	The plan includes teachers prompting students to discuss the SSI as a class or group, but does not provide opportunities for students to elicit and voice their own perspective on the SSI.

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.If authentic activity is not present or not connected to the SSI, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**
Students are engaged in inquiry-based learning activities that are tied to everyday life of the learners and mirror professional practices in STEM fields. Student ideas are shared beyond the walls of the classroom.	Students are engaged in learning activities that are tied to everyday life of the learners.	Students are engaged in learning activities that are not inquiry-based and connected to everyday life of the learners.

10) Dialogic Conversation

Provides opportunities for students to voice their own reasons (emotional tone, ideological, and conceptual positions) the speaker chooses in a specific contextIf dialogic conversation is not present or not connected to the SSI, then this component is scored as a zero.

Level 3	**Level 2**	**Level 1**

The plan includes opportunities for students 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.	The plan includes opportunities for students to engage with peers in discussions relating to the SSI.	The plan includes minimal opportunities for peer interactions between students relating to the SSI.
11) Metacognition Provides opportunities for students to use their learning experiences to transform (actions) themselves and others.If metacognition is not present or not connected to the SSI, then this component is scored as a zero.		
Level 3	**Level 2**	**Level 1**
Plan includes opportunities for students to reflect on their learning experiences and those of their peers in order to improve their own learning and to provide them with more ownership over their own learning.	Plan includes opportunities for students to reflect on their learning experiences and those of their peers in order to improve their own learning.	Plan includes opportunities for students to reflect on their learning experiences in order to improve their own learning.

Appendix 3: Interview Protocol

Semi-Structured Interview Questions (30-60 min)

Note for the Interviewer: Please state the teacher's name, date, time, and location of the interview at the start of your recording.

Interview procedure: Thank you for agreeing to participate as an interviewee sharing some of your experience participating in the SSI JUSTICE program over the past year. During the interview, you will be asked to respond to several open-ended questions. You may choose not to answer any or all of the questions. **This interview will be recorded and transcribed.** You may request a copy of the transcription. You may choose to stop participating in this interview and/or study at any time without negative consequences.

1. From the beginning of the project to now, in what ways has your knowledge of social justice evolved?

2. From the beginning of the project to now, in what ways have your teaching practices for integrating STEM teaching with social justice goals evolved?
3. In what ways, if any, do your students become involved in (civic engagement) in their community?
    a. What have you done to prepare your students?
    b. Thinking about last year and this year, in what ways do you think your teaching practices change in fostering civic engagement?
    c. Explain why you made those pedagogical decisions.

4. Scenario: A group of students are studying why people do not want to wear their masks.

    a. Social: the students decide that mask wearing should be optional because, if an authority figure doesn't do it, it can't be that important.

        - As a teacher, describe what your students are struggling to do?
        - What are you going to do to help your students evaluate multiple perspectives?

    b. Scientific: Schools are open and the teachers, administrators are unable to stop students from hugging. Students communicating in school under 6 ft apart. Administrators cannot enforce masks wearing policy.

        - As a teacher, can you please describe the scientific phenomenon that students do not understand?
        - Describe activities your students can investigate regarding this phenomenon.

    c. Discursive: A group of students decided to meet in their local pizza place to hang-out. They started to eat without masks inside the restaurant, which follows the 25% capacity limit.

        - There are multiple articles that show dining out and its effects on economy and physical and mental health. As a teacher, how will you guide your

students to scientifically evaluate and question information from different sources?

5. How did you support students' SSI knowledge/ability across the 3 elements of SSI (social, scientific, discursive) in your instruction and to give examples?
    a. Based on your unit, how would you modify it next time to better address these goals?
6. Is there anything else that I didn't ask, but you feel would be important to talk about?

Closing: Thank you for taking the time to participate in this interview. All information will be kept confidential. Please feel free to contact me with any questions or concerns you may have about this interview or this study.