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# Transforming STEM Instruction Through SocioScientific Issues Focused Professional Development[1]

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**Abstract**

This study reports the findings of a two-year intensive professional development (PD) program situated in the northeastern United States for secondary mathematics and science teachers to support them in transforming their STEM instruction to incorporate SocioScientific Issues (SSI). This PD focused on developing units of study that integrated student-centered, authentic learning experiences grounded in social justice issues. Findings indicate that after participation in the USTRIVE project, teachers displayed growth in their ability to incorporate components of the instructional framework for SSI introduced in the PD into their teaching. This is consistent with previous research that SSI-focused PD can increase teachers' knowledge of, and teaching practices toward SSI, resulting in more meaningful STEM learning experiences for students. As such, the USTRIVE PD model and framework may provide a useful guide for other SSI and social justice PD programs. Connections of these findings to student engagement, teachers learning, and challenges encountered in SSI implementation are explored.

**Keywords:** SocioScientific Issues, Social Justice, Professional Development, STEM Education

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## Introduction

Science, technology, engineering, and mathematics (STEM) topics provide a rich learning environment, with components of experiential and sensory learning, to better meet the needs of all student populations and multi-age groups (Johnson, Zielinski, Essary, Dean, Bartynski, & Macalalag, 2022). Yet, inequities across race and class persist in STEM subjects (Vakil & Ayers, 2019), particularly in urban settings (Yerrick, 2023). Despite numerous global reform efforts intended to improve the quality and equity of STEM education (National Research Council, 2012; Freeman et al., 2019), attaining greater equity in science education requires educators to reconceptualize the purposes and practices of STEM, including thinking critically about science content, pedagogical strategies, and views of who does science and for what purposes (Rodriguez & Morrison, 2019).

Teachers are fundamental change agents for STEM education in urban schools by connecting content to students' lives outside of school and providing students with opportunities for access to rigorous education (Andersen et al., 2022). However, implementing socially transformative practices demands significant changes to teacher understandings of what it means to know and do science (Finkel, 2018), which has made attaining any substantive change in attaining equity through STEM teaching difficult to achieve (Rodriguez & Morrison, 2019). Traditional STEM instruction is based in

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epistemological norms that emphasize social neutrality, and an authoritative knowledge base (Lenden et al., 2017), and curricula that devalue students' lived experiences (Calabrese Barton, 2003), all of which run counter to the goal of engaged, scientifically literate students. STEM reform efforts intended to enhance the applicability and authenticity of learning in STEM courses have succumbed to an increased focus on school accountability and teacher performance measures (Aikenhead et al., 2006) that reinforce instruction that emphasizes content and procedural knowledge to the detriment of students' development of functional scientific literacy, including critical thinking skills or their abilities to relate science to real-world problems (Zeidler, 2016). This is perhaps most troubling in economically depressed urban settings, where ineffective science instruction in low resourced schools have historically led to disengaged learners and perpetuated low achievement in traditionally marginalized populations (Tate, 2001; Yerrick, 2023).

Socioscientific Issues (SSI) is an instructional framework that shifts the traditional epistemologies of STEM from a product-orientation to emphasizing the process of student learning, thereby promoting scientific inquiry and individualized support (Johnson et al., 2022). Moreover, SSI provides a natural vehicle to support teachers in attaining the goal of countering traditional inequities and engaging students in STEM learning through real-world pressing issues delving into issues of injustice and ethics (Zeidler, 2014). Thus SSI provides a tangible pedagogical framework for teachers to utilize to address the goals of fostering students' epistemological flexibility (Ruppert et al., 2023) in order to address social justice science issues ranging from local (Morales-Doyle, 2017) to global issues of injustice and ethics (Johson et al., 2022; Zeidler, 2014). Professional development for SSI enhances teachers' ability to design STEM instruction incorporating real-world connections, critical thinking and student engagement (Johnson, Macalalag, & Dunphy, 2020). However, teacher familiarity and comfort with SSI varies greatly, and teachers require coursework or professional development to effectively integrate SSI into their instruction (Macalalag, Johnson, & Lai, 2017; Minken, Macalalag, Clarke, Marco-Bujosa, & Rulli, 2021).

While SSI is a useful instructional framework to enhance teachers' ability to design and implement a transformative STEM learning experience for students, relatively little research has examined SSI through the lens of social justice. It is with this in mind that the USTRIVE project was developed to provide middle and high school teachers from a large urban area in the northeastern United States with the knowledge and support to effectively implement SSI in their classrooms. This study reports the findings of a two-year intensive professional development (PD) program for middle and secondary mathematics and science teachers to support them in transforming their STEM instruction to be student-centered, authentic, and inquiry-based learning grounded in solving social justice issues (Rodriguez & Berryman, 2002; Zeidler, 2014). The questions guiding this study are;

1. *What variation is found in teacher use of SSI and social justice in their design of instructional units within the context of a 2-year professional development program?*

2. *What are teachers' experiences designing and implementing instructional units within the context of a professional development program focused on SSI and social justice?*

## Review of Literature

Three main areas of research are summarized below to contextualize this study within the broader field of STEM education. We begin with a summary of the literature about SSI, with particular discussion of the affordances of the SSI framework to explicitly attend to issues of social justice within STEM education. We follow with a consideration of how to support teacher professional growth for SSI, particularly through the framework of pedagogical context knowledge (PCK). This review details the challenges teachers face in advancing their PCK of SSI and the potential role of professional development to support PCK for SSI and to change instructional practice.

### Socioscientific Issues and Social Justice

The use of SSI is firmly situated in the landscape of educational reform and has been shown to have the potential to address the important social justice concerns within STEM education (Johnson et al., 2022). SSIs are ill-defined, debatable problems that require the examination of moral and ethical choices and knowledge of STEM to comprehensively understand and resolve the issue (Ratcliffe & Grace, 2003). Using SSI to frame instructional design shifts the traditional emphasis in STEM education from content acquisition to the process of student learning. SSI units of study are grounded in students' personal experiences, prior knowledge, and cultural background while promoting traditional STEM education goals, including content learning, skill development, and scientific literacy (Zeidler, 2014).

SSI may be conceptualized as consisting of three interrelated dimensions: social, scientific and discursive (Minken et al., 2021). The social dimension involves exploring the social and scientific dynamics of the issue, including understanding multiple perspectives, while the scientific dimension emphasizes student exploration and understanding of the STEM phenomena. The discursive aspects emphasize scientific skepticism and elucidating one's own position. SSI provides a unique avenue for students to engage in STEM content to address problems that may have a disproportionate negative impact on their lives. When STEM learning is framed through SSI, it opens opportunities for students to wrestle with diverse concerns that connect lived experience to issues beyond those of their immediate and familiar social circles (Castro, 2013; Ladson-Billings, 1995). For teachers, this means organizing curriculum and instruction in ways in which engaging in and understanding the complexity of the SSI is the driver of student learning, rather than content acquisition (Sadler, 2009). By engaging with and studying STEM content through SSI, students are encouraged to reflect on their own personal experiences, prior knowledge, cultural background, and belief system as they inquire about and engage with ill-structured problems and controversial issues (Zeidler, 2014). Such instructional goals provide authenticity for learning, contextualizes content, and promotes student agency to use science to address real problems. This reframing also provides an avenue for consideration of the social power dynamics underlying the SSI that may advantage or disadvantage particular groups based upon their social identities (Rodriguez & Berryman, 2002). Through the lens of social justice, SSI provides students with the opportunity to critique institutional, historical, sociocultural, and disciplinary structures that maintain and reinforce social inequalities in order to develop a deeper understanding of and/or draw conclusions about the SSI. Teaching STEM through issues framed in local contexts and with social justice aspects has been shown to have a powerful impact on students in a variety of facets, including critical thinking (Nuangchalerm, 2012).

Teaching through SSI necessitates that teachers shift their instructional practice to not merely use the social issues as a tool to foster engagement, but to reframe learning goals around moral, social and ethical issues in the STEM classroom (Gray & Bryce, 2006). In the present study, we utilize the framework of socioTransformative constructivistm (sTc) to integrate social justice into SSI instruction. The sTc framework emphasizes social positionality through dialogic conversation, reflexivity, and metacognition, grounded within authentic learning experiences that involve inquiry-based, hands-on, minds-on activities that are socio-culturally relevant and tied to the everyday life of the learner (Rodriguez, 2015). Thus, sTc provides a foundation for addressing SSIs reflecting structural inequalities, which students, and their communities, may lack the power to change (Rodriguez & Berryman, 2002) with the goal of developing students scientific agency to promote action through their use and application of scientific knowledge and skills developed in the classroom (Morales-Doyle, 2017).

**Supporting Professional Growth for SSI**

SSI requires a "fundamental reconstruction" of the rules and norms that dictate how STEM is typically taught (Zeidler et al., 2011). Most STEM teachers are unfamiliar with SSI and require coursework or professional development to effectively integrate social issues into their instruction (Macalalag, Johnson, & Lai, 2017; Minken et al., 2021). Given this significant pedagogical shift, most SSI research to date has centered on the implementation and impact of long-term professional development (PD) programs (Minken et al., 2021; Dawson & Venville, 2022; Saunders & Rennie, 2013).

Research has shown teachers' instructional design capacity and enactment of SSI varies greatly (Minken et al., 2021) reflecting differential knowledge and skills involved in SSI teaching as compared to traditional STEM instructional goals. Notably, teachers must confront and reconsider their epistemological orientation toward science, the role of the teacher and students in the classroom, pedagogical practices, and classroom culture (Ekborg et al., 2013; Lee et al., 2020). With respect to STEM epistemology, STEM teachers often struggle with extending the goals of learning beyond knowledge, facts, and procedures to include uncertainty in the classroom (Marco-Bujosa, 2021; Marco-Bujosa, Friedman, & Kramer, 2021; Ekborg et al., 2013; Lee et al., 2022). Other teachers may be uncomfortable or believe it is beyond the purview of STEM education to attend to moral, ethical, and social issues, preferring to focus on facts (Johnson, Batkie, Macalalag, Dunphy, & Titus, 2022). Connecting topics of social justice in STEM education can prove challenging for teachers given socialization into STEM norms that emphasize social neutrality and objectivity throughout their own educational experience. Teachers may experience little modeling of how to incorporate a critical lens in the STEM classroom to illuminate the ways in which STEM has been utilized as a tool of social and economic oppression, even in teacher preparation programs (Marco-Bujosa, McNeill, & Friedman, 2023; Rodriguez & Morrison, 2019). However, research has shown that directed professional development, aimed at facilitating and supporting SSI implementation, situated in development of teacher pedagogical content knowledge through focused experience with SSI, can positively impact classroom SSI practice (Johnson, Macalalag, & Dunphy, 2020; Marco-Bujosa, Mathers-Lowery, Johnson, & Araco, 2023)

SSI necessitates more student-centered pedagogical practices, including debates, discussions, and role playing, which shifts the role of the teacher from the provider of knowledge to a facilitator of student directed learning, a role that many teachers are uncomfortable with fulfilling (Johnson et al., 2022; Lee et al., 2020; Tidemand & Nielsen, 2017). Further, particularly for place-based SSIs, it can take time and experience to develop this knowledge of one's students and identify SSIs of interest and importance to the local community, and effectively leverage this knowledge in instructional design. Thus, making the SSI place-based may require students' perspectives to come out of the classroom itself (Marco-Bujosa, Friedman, & Kramer, 2021; Morales-Doyle, 2017). Thus, a collaborative atmosphere should be developed in the classroom to allow students to share alternative perspectives, ask questions, and build upon each other's knowledge, and make the SSI all the more meaningful to students (Lee et al., 2020; Sadler, 2011), pushing them to investigate and value diverse perspectives bringing a richness and new levels of engagement to the learning environment.

**Pedagogical Content Knowledge**

Pedagogical content knowledge (PCK) is accepted as an essential knowledge base for teaching (Shulman, 1986). Teachers must develop new knowledge and instructional practices, or pedagogical content knowledge (PCK). PCK is widely acknowledged as the central knowledge base for teaching. PCK has been conceptualized in a variety of ways, including teacher orientations toward teaching, knowledge of curricula, knowledge of assessment, knowledge of students, and knowledge of instructional strategies (Magnusson et al., 1999). Overall, PCK represents a dynamic perspective on the professional integration of professional knowledge and skills necessary for effective teaching, or, knowledge *for* practice, as opposed to knowledge *of* practice in recognition of the performative and situative nature of teaching and learning (Cochran-Smith & Lytle, 1992). As summarized by Gess-Newsome (2015), "PCK is both a knowledge base and a skill, recognizes the use of knowledge during and surrounding instruction, and establishes PCK and much of the related knowledge base as being grounded in the context of a specific topic…" (p. 39).

For SSI, effectively engaging students in open-ended, interdisciplinary, and social and ethical considerations, requires teachers to tap into a variety of different knowledge bases in different ways, including knowledge of students and the local context (Lee, 2016). There is a small and emerging body of literature exploring the elements of PCK of SSI and how to support growth in teachers' PCK of SSI. For example, Bayram-Jacobs and colleagues (2019) studied growth in teacher PCK of SSI through implementing researcher-developed SSI units. Findings indicate the importance of teachers': understanding of students' difficulties in SSI learning, knowledge of appropriate instructional strategies, and the ability to balance STEM content and SSI skills. In the context of a professional development program, Minken et al. (2021) highlighted the importance of content knowledge and specific knowledge of pedagogical strategies of SSI. Through professional development, teachers' knowledge of content and pedagogical strategies increased, yet struggled to balance the social and scientific elements of SSI instruction, as well as facilitating student interaction. Such findings indicate a key element of PCK of SSI involves fostering student action and agency, which is a central focus in justice-oriented teaching (Morales-Doyle, 2017; Rodriguez, 2015).

Despite the centrality of PCK in the field, and the growing attention to PCK for SSI in the science education research community (eg. Johnson et al., 2022; Bayram-Jacobs, et al., 2019; Lee, 2016/2022), PCK does not explicitly acknowledge the role of social justice in teaching and teacher learning (Dyches & Boyd, 2017). Embedding social justice within PCK acknowledges the ways in which "texts, pedagogies, and knowledge are ultimately dependent upon the focal topic, context, and teacher" (Dyches & Boyd, 2017, p. 479). In the present study, we utilize PCK as a guide for exploring the intersections of diverse knowledge and skills involved in teachers designing and implementing instruction integrating SSI and social justice in STEM teaching.

## Method

A mixed methods research design was utilized, integrating both quantitative and qualitative data to understand growth in teacher PCK (quantitative) and why and how these changes occurred (qualitative) (Leavy, 2017). This study represents findings from the first cohort, spanning two years of participation and data collection, from a larger a four year study whose overarching goal is to transform STEM education in high-need urban communities and in so doing provide meaningful opportunities for students to become empowered, STEM-literate citizens capable of advocating for change. The project spanned two years of professional development including workshops, institutes, field trips, professional learning communities, and conferences. Each aspect of the PD was designed to promote the USTRIVE framework for SSI instruction focused on social, scientific, discursive, and justice domains in ways consistent with best practices in professional development (Darling-Hammond & Richardson, 2009). The frameworks of SSI and sTc guided the content and implementation of the PD, as well as our interpretation of teacher experiences. Specifically, workshops and institutes were developed to provide teachers with opportunities to experience SSI lessons first-hand in the role of learners, provide opportunities for guided reflection on SSI pedagogies, and to provide time and support for development of SSI unit plans. PLCs were designed to extend this support in SSI curriculum development, to establish a community of practice, and to engage and support teachers as leaders in their schools. Field trips were planned to expose teachers to local resources that could potentially be leveraged in classroom SSIs. Finally, conferences were used to share and further develop the SSI curriculum developed in the program.

This study documented changes in teachers' instructional design for SSI as well as their developing understanding of designing and implementing instructional units within the context of a professional development program focused on SSI and social justice. We focused on one cohort of teachers participating in the USTRIVE program across two years. All participants were STEM teachers working in middle and high schools located in a large urban center in the eastern region of the United States. Two teachers taught math, while the remaining eleven taught science subjects. Subjects in which teachers created and implemented units of study included middle school science, Chemistry, Physics, Physical Science, Environmental Science, Biology, Computer Science, General Mathematics, Precalculus, and Geometry. SSI Units of study were designed throughout the USTRIVE PD experience and implemented twice in the classroom, once in each year of participation in the program. A broad range of teaching experience was represented spanning from 2 - 32 years. Two teachers had less than five years of teaching experience. Four of the teachers had between five to fifteen years of classroom experience, while seven teachers had greater than 15 years of experience.

**Table 1**
Participant Demographics

| Subject and Grade | Number of Teachers | Range for Years of Teaching | Subjects Taught |
|---|---|---|---|
| Science Grades 6-8 | 4 | 14-23 | Science, Service Learning |
| Science Grades 9-12 | 7 | 2-32 | Chemistry, Physics, Physical Science, Environmental Science, Biology, Computer Science |
| Math Grades 9-12 | 2 | 9-19 | Math, Precalculus, Geometry, |
| Total | 13 | 2-32 | 11 |

Four case study teachers were chosen to represent a variety of content areas and grade levels. These teachers worked in charter schools teaching middle and high school science or math. All designed and implemented SSI units with their students as a component of the USTRIVE program. Ms. Davis (15 years teaching) and Mr. Hernandez (4 years experience) taught middle school science, both in mainstream classes. Ms. Miller (9 years experience) taught high school math in a special education classroom and Ms. Smith (32 years experience) taught middle and high school science in an online alternative education program.

**Table 2**
Case Study Teacher Background Information

| **Teacher Name*** | **Teaching Assignment** | **Years Teaching** | **Educational Background** | **Unit Topic** |
|---|---|---|---|---|
| Ms. Miller | High School, Math Special Education | 9 | B.S. Mathematics M.S. Math Education | The Cost of College |
| Ms. Davis | Middle School, Science | 15 | B.S. Sociology M.S. Elementary Education | Solar Panels |
| Ms. Smith | Middle and High School, Science | 31 | B.A. Earth & Space/Geology M.A. Environmental Science | Global Warming |
| Mr. Hernandez | Middle School, Science | 4 | B.S. Social Work | Drug Abuse and the Legal System |

** pseudonyms*

Data collected from all participants included periodic "snapshots" of teacher-designed SSI units collected at the end of year one and a final unit plan submitted at the conclusion of teacher participation in the program. Unit plans were analyzed after years one and two using an a priori coding scheme based on the USTRIVE framework and associated rubric (Johnson, Macalalag, & Dunphy, 2020), which included 12 elements across the dimensions of *Social, Scientific, Discursive,* and *Justice*. Scoring was based upon a rubric aligned with the framework that included a three point scale (1= implicitly or minimally addressed: 3= explicitly and completely addressed) for each criteria. An outline of the USTRIVE framework domains including descriptions of individual rubric criteria are included in Appendix I. Two trained graduate research assistants independently coded each unit of study. The process of independent coding to attain interrater reliability involved each coder first reviewing and coding the unit of study independently, and then sharing and discussing the codes with each other. All disagreements were resolved after discussion. Overall interrater agreement was 98.7% for the first snapshot and 99.4% for the second snapshot prior to discussion and resolution of discrepancies.

**Table 3**
Sample Rubric Criteria

| **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. |

Following the analysis of snapshots for all participants, data from four teachers were explored to provide greater depth of understanding of the successes and challenges they encountered that may explain the findings for the incorporation of SSI into their instructional design. Qualitative data collected for this portion of the study included one observation of instruction, a post-observation interview, and an end of the year interview. Supplemental data included a background survey and unit plans collected in December (prior to teaching their unit) and May (after teaching their unit), respectively. The data was analyzed through open coding procedures (Miles et al., 2014) to identify salient themes representing participants' experiences interpreting and enacting the USTRIVE framework in the context of their own instructional approach and classroom contexts. An iterative coding process was implemented with the research team coding individual data sources and meeting to discuss and resolve discrepancies. This was an interactive and collaborative process taking place over the course of weekly coding discussions involving separate readings by four independent researchers, each focused on a different data source, across one semester. These discussions resulted in a preliminary coding scheme which both informed and was refined through analyzing additional data sources.

## Findings

This study sought to address the following research questions and findings are presented by research question:

1. *What variation is found in teacher use of SSI and social justice in their design of instructional units within the context of a 2 year professional development program?*

2. *What are teachers' experiences designing and implementing instructional units within the context of a professional development program focused on SSI and social justice?*

### RQ #1: Variation and Trends Across Units of Study

Across participants, means for rubric ratings were calculated for each of the 12 elements and the four dimensions of the USTRIVE framework rubric for units completed in year one (May 2022) and year two (May 2023). For year one (May 2022), the strongest domain was *Scientific* (*M*=2.90, SD=0.28), while the weakest domain was *Discursive* (*M*=0.96, SD=0.83). Among individual elements, *exploration* *of SSI*, *knowledge: explore and explain the underlying scientific phenomena and/or concepts in mathematics, PCK: instructional strategies on exploration of SSI, and authentic activity* were highest (*M*=3.0, SD=0.0), while *employ reflective skepticism* was the lowest element (*M*=0.54, SD=1.05).

The analysis of the units of study at the end of year one identified those areas of the rubric where teachers had the most potential for growth. As such, the PD was revised to target those areas and provide additional support to teachers. As teachers began their second year in the program, they had direct instruction and practice with developing lessons, activities, and assessments focused on three elements of the rubric: *employing reflective skepticism, elucidating their own position/solution,* and *reflexivity*. For year two, the strongest and weakest domains were once again *Scientific* (*M*=3.00, SD=0.0) and *Discursive* (*M*=1.85, SD=0.59) respectively. It can be noted that growth was seen in both of these domains between years one and two. Five elements were highest (*M*=3.00, SD=0.0): *identify the issue, issue system dynamics*, *knowledge of scientific phenomenon*, *PCK of scientific phenomenon,* and *STEM modeling*. The element *employing reflective skepticism* was the lowest (*M*=0.85, SD=1.21).

The element, *elucidate own opinion/solution*, is the area of the rubric where teachers displayed the most growth (2022, *M*=1.38, SD=0.96; 2023, *M*=2.85, SD=0.38). This component addresses the inclusion of activities in the unit of study that allow students to use data to support their position, the strengths and weaknesses of their claims, or identify their biases or limitations related to the SSI discussion. While no direct instruction was provided in the second year of the PD to address this element, an emphasis was placed on the other element within the *Discursive* domain, *employ reflective skepticism*, (2022, M=0.54, SD=1.05; 2023, M=0.85, SD=1.21). It follows that since teachers increased the opportunities for their students to analyze, critique, or be skeptical of any information connected to their SSI discussion, teachers would then provide occasions for students to use data to explain their position, the strengths and weaknesses of their claims, or identify their biases or limitations connected to their SSI discussion.

Three elements, *authentic activity* (2022, *M*=3.00, SD=0.00; 2023, *M*=2.92, SD=0.28), *dialogic conversation* (2022, *M*=2.92, SD=0.28; 2023, *M*=2.85, SD=0.55), and *metacognition* (2022, *M*=2.77, SD=0.44; 2023, *M*=2.69, SD=0.75), reflect a slight decrease between years one and two. All three of these elements are within the *Justice* domain of the rubric. This finding is surprising as social justice was the focus of workshops and PLCs in the second year of the PD. Additionally, teachers received a textbook geared toward including social justice in the curriculum and were tasked with developing a social justice lesson or activity. Teachers also engaged in monthly discussions about a local STEM issue using a justice lens. Each of these areas scored high overall and the changes were small and not statistically significant. The slight decreases in these areas may indicate a shift in focus of our PD sessions toward areas that scored lower in analysis, and may warrant reflection on our justice-focused programming within the PD.

The mean remained the same (*M*=3.00, SD=0.00) between year one and year two for three elements of the rubric, *exploration of SSI, knowledge of scientific phenomenon, and PCK of scientific phenomenon.* The main focus of the USTRIVE project is the incorporation of SSI into the STEM curriculum and emphasis was placed on helping teachers develop a unit of study based on an SSI relevant to their students. This finding demonstrates that the PD is effective at instructing teachers in how to successfully incorporate an SSI into their STEM curriculum. While the range of teaching experience varies for the participating teachers, each teacher had an educational background in a STEM discipline. This may account for the consistently high rating (*M*=3.00, SD=0.00) across the two years of the PD in the two areas of the rubric that addressed understanding the scientific phenomenon or mathematical concept: *knowledge of scientific phenomenon* and *PCK of scientific phenomenon*.

**RQ #2: Teacher Experiences in Designing and Implementing SSI Units**

The qualitative analysis of four individual participants revealed three superordinate themes that best reflected teacher experiences: *Successes*, which teachers interpreted as positive changes in their instruction and student learning; *Opportunities*, in which teachers expressed hope, inspiration, or concrete strategies to improve upon in the second year; and *Challenges*, reflected in personal capacity to integrate SSI and STEM content.

***Success: Student engagement***

Across interviews, teachers described a common experience of enhanced student engagement. Teachers attributed this engagement to the connection of the content to real-world issues outside of the classroom. For example, Ms. Smith recognized the positive impact on student engagement of focusing on a real-world issue, such as global warming. "I actually got a whole lot of participation with the unit and especially linking it to things that… personalize it, like the global warming issue with their cell phone and driving and things like that." Ms. Miller, who taught in an all-male charter school with a mission of 100% college attendance, also saw the benefit of using mathematics to explore the issue of racialized differences in college debt and future earning potential in her unit. In her post-observation reflection interview, she emphasized that she learned the importance of relevance. "When students do really like that… really understand the concept or skill they have to… understand its meaning and like it has to mean something to them."

Teachers not only observed the positive impact on student engagement, they also highlighted the benefits of this approach on their students' learning of more traditional content. For example, in the post-observation interview, Mr. Hernandez made the following observation:

So yeah, they were in it and they were talking about it in the hallway so I think just the excitement of it- it helps if you also make it– you know make it fun and not all about the facts. Because what I noticed is that- and I really enjoyed this- is that at the end of it, they came out knowing all the things I wanted them to know from the beginning anyways.

His students were engaging in the content in ways he had never observed before, discussing content outside of the class time and space. He emphasized that by using the framework, he enhanced student learning of content. As he observed, "I think that if anything, [students] struggled with things that weren't related to SSI. They actually looked forward to the SSI lessons." For the participating teachers, success was evaluated based on the contrast between more traditional approaches to teaching STEM disciplines, which tend to focus on student acquisition of knowledge, and SSI, which placed students at the center of the learning process.

***Challenges: Connecting SSI and STEM content***

Participating teachers struggled to integrate the SSI and STEM content in their units of study. For example, the teachers noted that in the first year, while they developed a unit focused on SSI, their instruction was not cohesive and integrated, resulting in a disjointed learning experience in which students were exposed to SSI instruction on some days, followed by more traditional STEM content. The teachers themselves felt that integrating SSI into STEM lessons was a challenge. This sentiment was expressed by Ms. Davis, who commented, "I've also been keeping my science curriculum somewhat related to the [SSI] unit, but other times I feel like it's two separate things being taught in its own category rather than it overarching and coming together as one." Similarly, Mr. Hernandez explained how he struggled to address the social and the scientific together due to limited instructional time, ending up with a more social-focused class or a more science-focused class. He said, "I only have them for about an hour at a time, there are days where we're focused on the social justice aspect of it, and there are days where we're focused on the science aspect of it." In the end of year interview, Ms. Smith observed that the social elements were difficult to integrate and felt inauthentic; "the biggest problem for everything that I'm teaching is coming up with a social justice [issue] to sort of match the concept." Integrating SSI into math lessons also proved to be challenging. Ms. Miller stated,

"And then just trying to find ways to develop more, put more of their… content area math in the project. 'Cause I think when it came to… talking like… the concept idea is that the socio science issue and… discussing perspectives and I like ideas around it, it was it was there but, there wasn't a lot of math to it. Just finding more ways to like really incorporate more of the math part that we did this school year."

Thus, while teachers were open to designing lessons intended to enhance relevance and applicability, they had difficulty connecting issues to content. This may be connected to the slight decline in social justice codes observed in the quantitative analysis of teacher units. As participating teachers progressed in the program, some realized that their focus had primarily been on building the SSI and as they attempted to bridge the gap between their chosen socioscientific issue and the associated content, they began to shift their focus back towards the content. These shifts are not entirely surprising as teachers navigate new practices and project developers respond to teacher feedback and hence shift focus to address teacher needs. As professional development focus changes, it follows that the teachers' focus will also follow.

**Table 4**
Incorporation of social justice into teaching of STEM subjects after year 1 of participation in the project

| Level of Incorporation | Number of Teachers |
|---|---|
| 1 - never | 1 |
| 2 - rarely | 2 |
| 3- sometimes | 7 |
| 4 - frequently | 1 |
| 5- always | 2 |
| Average | 13 |

***Opportunity: Teacher learning***

All four teachers recognized that their own learning was central to effectively designing and implementing instruction using the framework. Central to teachers' experiences with the program was developing an awareness of their own learning needs. Across the interviews, teachers described themselves as "novices" and "new" to SSI, yet also maintained a positive perspective on their own capacity to improve. At the end of the year, Mr. Hernandez stated, "It's different because before we were teaching principles, we were teaching the foundational things but we weren't teaching how to apply it" indicating self-reflection on his teaching and how his practice has grown. Similarly, in the interview following her observation, Ms. Miller reflected, "I am learning through the process how can I do this better?" Each of the four case study teachers came to this realization after teaching the units they designed. Ms. Davis said, "I think if I was more intentional with my instruction goals, a lot of the lessons that lead to the objective would have been better accomplished." These quotes indicate the importance of deliberate planning, guided by the pedagogical tools and transformative mission advanced in the PD program. Teacher statements also indicate the importance of sustained support for teachers as they begin to implement their SSI plans. Through providing support and guidance during the initial implementation of the lessons, a time these participants identified as vital to their understanding of SSI implementation and teacher learning, the program was better able to foster pedagogical effectiveness.

## Discussion

Overall, after two years of participation in the USTRIVE project, teachers displayed growth in their ability to incorporate components of the SSI/sTc framework into their STEM curriculum. This finding supports the research that directed professional development in SSI can provide teachers with the knowledge, resources, and experience, to become comfortable and effective at SSI implementation (Johnson, Macalalag, & Dunphy, 2020). By incorporating SSI into STEM classrooms, teachers experience a shift in their knowledge of, and teaching practices, of SSI, which ultimately provides meaningful contexts for students to learn and practice STEM concepts (Zeidler et al., 2005). Through participation in the USTRIVE PD program, teachers gained first-hand experience in SSI based lessons from the perspective of learners and were then given time and opportunity to reflect on these experiences as educators. They were supported in the development and implementation of SSI unit plans both in USTRIVE events and in their classrooms. This longitudinal support over the course of two years of participation through institutes, workshops, and PLCs opened the door for successful classroom implementations and effectively shifted beliefs towards SSI and classroom practice. As such, the USTRIVE PD model and framework may provide a useful guide for future professional development programs aimed at SSI and social justice. While this study did not include pre-service programs, similar directed lessons may also be useful for pre-service teacher preparation programs to provide foundational knowledge and experience for SSI implementation.

The findings also indicate teachers had an overall positive experience incorporating SSI and social justice into their teaching practice. These teachers engaged in reflection on their own teaching to identify opportunities to improve, illustrating the desire to transform their own approach to STEM education to benefit their students, despite the inertia in math and science education to reinforce more traditional, elitist authoritative forms of knowledge (Rodriguez & Morrison, 2019). However, teachers encountered significant external barriers within middle and high schools that structure and restrict teachers' pedagogical freedom. Similar to other research, findings indicate accountability pressures in urban schools emphasize core content (Hinnant-Crawford, 2019), which may discourage teachers from engaging in this transformative work. Therefore, a central element of PD intended to transform student opportunities to learn STEM will involve preparing teachers to effectively navigate and challenge these educational structures (Johnson, Macalalag, & Dunphy, 2020). In learning about SSI and social justice, teachers are confronting the culture of STEM, turning away from STEM as being just the facts. This was entirely new for some of our participants and necessarily involved shifting teaching practices from teacher-centered to student-centered. This is outstanding news for us as we prepare to design our next year of professional development as it provides a deeper understanding of where our teachers may be starting from and informs how to streamline development in SSI instruction for both continuing and new participating teachers.

This study explored the impact of an instructional intervention designed to transform STEM education and directly address the inequalities and inaccessibility of traditional science education for students of minoritized identities. It provides valuable insight into teacher experiences engaging in this transformative work that can be utilized by other teacher educators in the design of learning experiences that dismantle traditional approaches to STEM education (Finkel, 2018; Rodriguez & Morrison, 2019). Thus, the findings offer insight into how inequities in science education can be reformed through teacher education. Slight drops in rubric scoring, particularly in the *Justice* components of the rubric, may be due to teachers struggling with the complexity of implementing these new ideas into their STEM pedagogy or existing ideas in new ways, a finding consistent with prior research (Darling-Hammond & Richardson, 2009). It is important to note that all participants chose to join the USTRIVE. The fact that they self-selected into the program and remained active participants throughout two years of intensive professional development indicates a desire to learn and implement new classroom practices that are better for their students. Yet each participant's learning started from different places and perspectives as did their reasoning for participation and their interpretation of the impact on their students. While all participant teachers observed enhanced student engagement, which motivated their learning and professional growth, the teachers with more experience in social justice work tended to look at engagement beyond increased participation to increased depth in application, particularly outside of the classroom. This again serves to inform how to best engage incoming teachers in PD activities based on their previous experience.

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## Appendix I

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| **Domain 1: Social Aspects** |
| **1) Exploration of SSI**<br>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). |
| **2) Consider issue system dynamics**<br>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**<br>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**<br>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). |
| **5) Engage in STEM modeling**<br>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** |

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| **6) Employ reflective scientific skepticism**<br>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**<br>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**<br>**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 in Rodriguez. & Morrison, 2019; Zeidler, 2014).** |
| **9) Authentic Activity**<br>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**<br>Provides opportunities for students to voice their own reasons (emotional tone, ideological, and conceptual positions) the speaker chooses in a specific context. |
| **11) Metacognition**<br>Provides opportunities for students to use their learning experiences to transform (actions) themselves and others. |