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Making strides: Findings from an SSI focused STEM professional development project

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Abstract

Understanding STEM Through Integrated Contexts in Everyday Life (USTRIVE) is a four-year, NSF funded project with the aim to address inequities in STEM education by fostering culturally responsive and innovative STEM pedagogies. Collaborating with four universities and a regional consortium, the project targets 7th through 12th grade STEM classrooms in high need urban communities. USTRIVE focuses on SocioScientific Issues (SSI) and SocioTransformitive Constructivism (sTc) to integrate real world social justice topics into STEM education. The project involves thorough professional development for teachers, focusing on instruction design and delivery, and SSI implementation, aimed to enhance pedagogical content knowledge (PCK) and empower students to become STEM- literate citizens. Research has shown that USTRIVE's PD has positively impacted teacher confidence, cultural awareness, and ability to incorporate SSI into their lessons, leading to increased student engagement and critical thinking. There are still challenges that teachers face while integrating discursive elements into the classrooms and overcoming curricular barriers. Ongoing research continues to explore USTRIVE's impact on teacher leadership and student development as capable agents of social change.

Keywords: STEM, SocioTransformative Constructivism, USTRIVE

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Introduction

The Understanding STEM Through Integrated Contexts in Everyday Life (USTRIVE) project is a four-year NSF DRK-12 Grant funded project aimed at addressing societal inequities in science, technology, engineering, and mathematics (STEM) education through fostering the implementation of innovative and culturally responsive STEM pedagogies. The project is a collaborative effort between four universities and a regional consortium of STEM educators located in the northeastern United States. The USTRIVE project targets innovations in instructional design and teacher professional development to advance STEM learning through implementation of SocioScientific Issues (SSI) into middle and high school STEM classrooms with the overarching goal to transform STEM education in high-need urban communities in a large urban area and in so doing provide meaningful opportunities for students to become empowered, STEM-literate citizens capable of advocating for change. Teaching that incorporates SSI diverges from more traditional pedagogies by engaging students in moral and ethical decision making, situated in in STEM contexts, to foster deeper engagement and foster the development of functional scientific literacy (Zeidler et al., 20025).

STEM topics have unique potential to provide a rich learning environment, with components of experiential and sensory learning, to engage all student populations and multi-age groups (Johnson et al., 2022c). Education reform has consistently called for STEM courses to equip students to participate in scientific discourse on public policy issues with fellow citizens and for teachers to foster connections across STEM subjects (Rutherford & Ahlgren, 1991; National Research Council, 2012). However, while there is a clear consensus that STEM education should develop the ability to deal with authentic, real-world scientific issues as they appear in student lives, there is no similar level of agreement as to what classroom experiences best facilitate that outcome. STEM courses often succumb to increased focus on school accountability on teacher performance measures (Aikenhead, Calabrese, & Chinn, 2006) resulting in STEM instruction that emphasizes content and procedural knowledge to the detriment of students' development of critical thinking skills or their abilities to relate science to real-world problems (Marco Bujosa, Levy, & McNeill, 2020; Zeidler, 2016). This is perhaps most evident in economically depressed urban settings, where poor science instruction and disengaged learners in low resourced schools lead to school failure or low achievement (Morales Doyle, 2017). Thus, inequities persist in STEM subjects across race and class (Vakil & Ayers, 2019), particularly in urban settings (Marco Bujosa, McNeill, & Friedman, 2020; Yerrick, 2023). Despite numerous reform efforts intended to improve the quality and equity of STEM education (NRC, 2012; Freeman, Marginson, & Tytler, 2019), attaining greater equity 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; Johnson et al., 2022a).

It is with these inequities in mind that the USTIVE project was developed to foster innovative pedagogical practices with a social justice focus into STEM classrooms. Recognizing teachers as fundamental change agents for STEM education in urban environments (Johnson et al., 2024), USTRIVE focused primarily on training in curriculum development and support in classroom implementation of SSI based units of study. This kind of shift in practice to socially transformative planning and pedagogy requires significant changes to understandings of what it means to know and do science (Finkel, 2018), which makes attaining substantive changes difficult to achieve often resulting in a perpetuation of traditional STEM classroom practices (Rodriguez & Morrison, 2019). As such, this project sought to inform best practices in teaching STEM subjects to engage underserved populations as well as effective means of preparing and supporting teachers in taking on this task, thus bridging a gap in the existing literature. Traditional STEM instruction is founded in epistemological norms that emphasize a culture-free view of STEM subjects with an authoritative knowledge base and curriculum that devalues students' lived experiences (Calabrese Barton, 2003). This is in direct opposition research based pedagogical strategies with the goal of engaged, scientifically literate students (Zeidler, 2016). To improve academic achievement and access to STEM career paths for students from historically marginalized identities, transformative frameworks must be introduced to guide curriculum and instruction that increase equity and access in STEM education (Morales Doyle, 2017). In the USTRIVE project, this kind of framework, based on a conjunction of SSI (Zeidler et al.,

2005) and SocioTransformative Constructivism (sTc) (Rodriguez, 1998) was developed to serve as the theoretical guide for the project's efforts to enhance teacher instructional design capacity. An extensive professional development (PD) program was designed and implemented, aimed at fostering effective teachers' practices and expanding their pedagogical content knowledge (PCK) (Magnusson, Krajcik, & Borko, 1999) with the application of the SSI/sTc framework.

SocioScientific Issues

SSI are ill-defined problems that are debatable, have a basis in authentic, real-world science, and necessarily include moral and ethical choices. SSI involves authentic, real world, science-based societal issues that, when studied, require students to develop scientific content knowledge, scientific literacy tools, as well as moral and ethical reasoning skills (Dolan, Nichols, & Zeidler, 2009). SSIs can include a wide variety of topics such as how GMOs impact access to food and human health in urban communities, vehicle speed limits and fatalities in cities, biodiversity as it relates to lawns and public spaces, school policy regarding concussions, AI in classrooms, and many more (Johnson et al., 2022b). While they require scientific knowledge to understand, they cannot be resolved through science alone and require students to delve into all aspects of complex sociocultural issues (Ratcliffe & Grace, 2003; Johnson et al., 2022c). As such SSI can provide meaningful contexts for students to learn key STEM concepts and practices in authentic, meaningful ways (Zeidler et al., 2005). As an educational reform, SSI parallels other reform efforts, such as teaching through science inquiry, the engineering design processes, technological literacy, mathematics and computational thinking, and environmental education, while remaining distinct in focus and application (Johnson et al., 2022a). As with science inquiry, SSI promotes development and testing of scientific models through evidence-based argumentation and allows students to identify arguments and counter arguments based on models (Abd El Khalick et al., 2004; Albe & Gombert, 2012). This promotes understanding of the nature of science, that scientific knowledge is tentative and relies on iterative science inquiry and evidence-based explanation and argumentation from people of all cultures (Bell, Flick, & Lederman, 2006). Unlike science inquiry, which focuses on the systematic and iterative process to understand the natural world (National Research Council, 2012), SSI cases can extend to areas such as citizenship education (Barrue & Albe, 2013), sociopolitical aspects, morals, character, and values (Zeidler, 2016; Lee et al., 2013). Zeidler (2016) argued that this extension is necessary to develop students' functional scientific literacy through which they are better able to gain a more comprehensive understanding of science in the context of real world, culturally relevant topics, and apply their understanding to evaluate information, examine multiple perspectives, consider moral and ethical dilemmas, and recognize cultural backgrounds before making sound decisions. Other researchers have argued that if scientific literacy is indeed a central and important goal of science education (NGSS Lead States, 2013; Johnson et al. 2022a), "then scientific literacy must entail, at least in part, the ability to thoughtfully negotiate SSI and contribute to discourse regarding these topics" (Sadler et al., 2006, p. 354). The social and subjective nature of SSI provides a direct means for students to apply scientific discourse tools to address key aspects of the nature of science (Zeidler et al., 2002). It is important to note that scientific discourse includes more than just ways of speaking, but a larger set of issues. As defined by Gee (1987) "discourse is a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group" (p.1). Gee's definition speaks to the authenticity that is inherent in SSI lessons. SSI includes the use of "personally relevant, controversial, and ill-structured problems that require scientific, evidence-based reasoning to inform decisions about such topics" (Zeidler, 2014, p. 699). Thus, SSI provides a strong framework for engaging students and teachers in meaningful and relevant scientific discourse in the development of functional scientific literacy (Macalalag, Johnson, & Lai, 2019) and empowering students to consider how science-based issues and decisions made concerning them reflect moral principles present in their own lives and the physical and social world around them (Zeidler et al., 2005).

SocioTransformative Constructivism

SSI topics are, by their nature, inclusive because all students can relate to real world controversies and, by their controversial nature, often address issues of power, inequity, and social justice. Research indicates teachers tend to have difficulty shifting their understanding of STEM away from facts and a more traditional, culture-free view of STEM topics (Ekborg et al. 2013; Lenden et al., 2017), which is counter to effective SSI and social justice pedagogy. When asked to reconceptualize their view of STEM instruction to models necessary to effectively integrate social justice pedagogies, teachers may exhibit resistance to ideological change and/or resistance to pedagogical change from the traditional mindsets. Resistance to ideological change stems from feelings of guilt, disbelief, defensiveness, and shame that teachers often experience when asked to confront issues of social justice and oppressive social norms, like racism, in class discussions (Johnson, 2011). Resistance to pedagogical change refers to ways teachers manage the conflicting classroom expectations, like covering curriculum, maintaining class control, navigating expectations of administration or supervisors, and implementing student-centered, constructivist class activities (Rodriguez & Kitchen, 2005). Rodriguez (1998) developed his sTc framework as a countermeasure to these two types of resistance he observed in preservice science teachers. sTc can also be used as a powerful framework for understand how issues of social justice can and should be addressed in STEM classrooms (Johnson et al., 2022a) and for engaging teachers and students in empowering dialogues that can lead to a deeper understanding of subject matter and to the application of content knowledge in socially relevant ways (Rodriguez & Berryman, 2002). The sTc framework draws from multicultural education as a theory of social justice and from social constructivism as a theory of learning (Rodriguez, 1998). These two viewpoints intersect where students' voices and sociocultural perspective are not recognized or validated in their educational process. sTc provides a teaching and learning orientation that acknowledges how issues of power, gender, and equity influence not only the curriculum covered but also how and to whom it is taught (Rodriguez & Berryman, 2002). Rodriguez (1998) noted that social constructivism tends to overlook the concept of student agency as a means of connecting new knowledge with transformative action. sTc emphasizes that school curriculum must present socially relevant, challenging new knowledge to engage in meaningful dialogue to become active participants in their communities (Rodriguez & Berryman, 2002). It provides a framework for viewing social knowledge construction with the expressed purpose of addressing the injustices facing learners each day in the educational system. sTc is organized into four elements: dialogic conversation, authentic activity, metacognition, and reflexivity (Rodriguez, 1998)

The first element of sTc, dialogic conversation, moves the learner to a recognition of how every individual's voice engages in conversation with others to create context-relevant meaning, moving beyond understanding of what is said to understanding the speakers' reasons for saying it based on his or her specific context (Rodriguez & Berryman, 2002). Bakhtin (1986) provided a powerful description of dialogue in our human experience: "The single adequate form for verbally expressing authentic human life is the open-ended dialogue. Life by its very nature is dialogic. To live means to participate in dialogue: to ask questions, to heed, to respond, to agree, and so forth" (p. 293). Unfortunately, the traditional, didactic style instruction is often lacking this necessary component of human life (Jewitt et al., 2001).

Dialogic conversations are situated within authentic classroom activities. The sTc framework defines authentic activities as spaces in which students explore how topics under study are socially and culturally relevant and connected to their lived experience (Rodriguez & Berryman, 2002). Authentic work is complex and socially or personally meaningful to the learner involving the original application of knowledge and skills, beyond the routine use or memorization of facts and procedures (Newmann, Bryk, & Nagaoka, 2001). It also entails inquiry into a particular problem and results in a product that has meaning or value beyond success in school (Rodriguez & Berryman, 2002). When teachers base pedagogical practices around assignments requiring higher order thinking, in-depth understanding, elaborated communication, and connections to students' lives outside of the classroom, students will produce more complex intellectual work (Newmann, Bryk, & Nagaoka, 2001).

Understanding how and why classroom topics and teaching strategies are chosen and implements requires metacognition. Bransford and Donovan (2005) defined metacognition as the ability to monitor one's own level of understanding and to decide if it is or is not adequate. Metacognition represents thinking about one's own thinking and identifying deficiencies in patterns of thought. Rodriguez (1998) expands on this definition by adding critical and reflective questions such as "Why am I learning about this topic?" "Why am I learning these concepts in this way?" "What control [voice] do I have in how to proceed?" and "By what other method(s) can I learn this subject matter best?" (p. 600). The goal then is to move closer to a sense of consciousness and agency in one's own ways of learning.

Related to metacognition, reflexivity is a critical process through which social location, ideological location, and academic location are explored regarding perceptions of what is worth learning. Social location refers to ethnic or cultural background and socioeconomic status (Rodriguez & Kitchen, 2005). Ideological location represents values and belief systems while academic location represents academic attainment levels and skills. Through a critical approach to viewing our own positionality in context, we are better able to address inequity and understand how we can act on new knowledge to bring about social change (Rodriguez & Berryman, 2002).

The USTRIVE Project

Despite the general acceptance of culturally responsive pedagogies as effective for engaging traditionally underserved populations in STEM classrooms, research has shown that it is very difficult to sustain large-scale pedagogical change from more traditional methodologies (Yerrick, Parke, & Nugent, 1997; Rodriguez, 2005). To address this challenge, a research team from four universities in the northeastern United States, in conjunction with a regional consortium for STEM Educators, proposed the collaborative design and development research project USTRIVE. This four-year project aimed to facilitate innovations in instructional design and teacher professional development to advance STEM learning, particularly in urban classrooms. The National Science Foundation (NSF)-funded USTRIVE project was designed to transform STEM education in high-needs urban communities in the region surrounding a large urban center in the northeastern United States and in so doing provide meaningful opportunities for students to become empowered, STEM-literate citizens capable of advocating for change. At the time of the writing of this manuscript, the project was in year three of four with two cohorts of fourteen middle and high school STEM teachers having completed the two-year cycle, one cohort of twenty four entering their second year, and a final fourth cohort in the recruitment process. These teachers work in districts serving an estimated 50,000 students in 7^{th} to 12^{th} grades, while the teachers themselves serve nearly 3,000 7^{th} to 12^{th} graders (Macalalag, 2021).

The USTRIVE team developed an intensive two-year PD program seeking to integrate SSIs in STEM curricula using the social justice lens of sTc. The program aimed to foster and support the development and application of high-quality STEM instructional materials integrating locally relevant SSI into STEM teaching reflective of the following goals:

(1) development, implementation, and reflection on STEM units of study that combine SSI and aspects of social justice

(2) cultivation of pedagogical content knowledge (PCK) in SSI and social justice teaching orientation and instructional strategies

(3) acquisition of instructional design capabilities, specifically in developing and implementing lesson plans, assessments, classroom resources, and reflections (i.e., units of study) that emphasize developing, testing and revising STEM modeling and the discursive nature of SSI

(4) fostering functional scientific literacy of students through a cultural competence and sociopolitical consciousness instructional lens.

(5) creation of a repository of classroom and curricular for use by teachers who adopt SSI and social justice into their STEM teaching.

(6) cultivation of diverse partnerships including school administrators, classroom teachers, community-based informal learning settings, and university faculty, to engaged in supporting high-need schools and classrooms.

(Arcadia University, 2024)

These six goals comprise the heart of the USTRIVE program. The 200-hours-plus PD program provides teachers with workshops, professional learning communities (PLCs), and on-site support during implementation, funding for classroom materials, field trips, an eight-day long summer institute, and an annual conference. During the first year of participation, teachers worked to plan, prepare, and revise SSI units of interest to their students through participation in the summer institute, workshops, PLCs, field trips, classroom visits, etc. Units of study were implemented in the spring of their first year of participation. During the second year, they continued to review their units, acted as mentors to new participants, and developed as leaders in their schools. Multiple opportunities were provided for teachers to experience firsthand what their students experience as they engage with the USTRIVE SSI/sTc units (Varma, 2024). The project team also collected teacher and student research data while an external evaluation partner provides formative and summative evaluations of the project outcomes. Results from research published from the first three years of this data are synthesized and reported in this report.

A USTRIVE SSI/sTc framework (Johnson et al., 2022b) was developed to guide unit development and research analysis. The framework was developed from elements of the work of Sadler, Friedrichsen, and Zangori (2019) on teaching SSI, in which teachers prepared units to enable students to explore basic scientific phenomena while also engaging in scientific modeling, including considerations of system dynamics, applying strategies that promote information and media literacy, differentiating and synthesizing multiple perspectives while clarifying their positions or solutions. The USTRIVE SSI/sTc framework incorporated these components with aspects of the sTc framework to inform social justice aspects of the project, specifically dialogic conversation, authentic activity, metacognition, and reflexivity. From the USTRIVE SSI/sTc framework an associated rubric for planning the lessons/ units was created and shared with all participating teachers and served as a guide for the preparation of unit plans and the classroom observations of the teachers. The research team revised the framework in spring 2023 based on external feedback to include a more qualitative stance (Appendix 1). Both the framework and the unit planning rubric/guide are organized into four domains: *social aspects, scientific aspects, discursive aspects, and justice aspects.*

The framework and rubric guided both application and research portions of the project. The project was designed to explore six overarching research questions in terms of both teachers participating in the project and their students.

For Teachers:

1) In what ways, if any, do program activities support in developing teachers' PCK in instructional strategies with emphasis on the three elements of SSI: scientific, social, and discursive?
2) How does the teachers' PCK of students' understanding of SSI impact civic engagement as social agents of change?
3) In what ways, if any, do teachers' dispositions change towards teaching with sTc?
4) What factors support and inhibit teacher leadership to promote SSI/sTc?

For Students:

5) How do justice-centered STEM lessons help students to develop elements of SSI (e.g. moral and ethical reasoning, scientific skepticism, STEM inquiry/modeling, SSI discourse/argumentation)?
6) In what ways, if any, do students exhibit civic engagement as social agents of change through SSI?

Pedagogical Content Knowledge in SSI

Effective teaching, especially when integrating innovative educational models like SSI and sTc, demands the cultivation of teachers' pedagogical content knowledge (PCK) in planning, instruction, and reflection of key components (Bayram Jacobs et al. 2019; Minken et al., 2021).

Shulman's PCK framework, proposed in 1987, describes the specialized knowledge teachers employ to inform their instructional decisions, comprising subject matter content knowledge, curricular knowledge, and the intersection of both in pedagogical content knowledge (Shulman, 1987). Subject matter content knowledge refers to the specific content area being taught, with different subjects requiring distinct substantive and syntactic presentation and discussion approaches (Schwab, 1978). As such, Shulman (1986) argued that expert teachers' understanding of their subject matter must be at least as great as their counterparts practicing in the field. Pedagogical knowledge encompasses general understanding of learning, instruction, and curriculum, while curricular knowledge entails familiarity with teaching tools (Shulman, 1986). As an example, technology or alternative texts, and how these can be applied to various topics presented in the classroom would represent forms of curricular knowledge (Yerrick & Johnson, 2011). Shulman (2004) described curriculum as "the full range of programs designed for the teaching of particular subjects and topics at a given level" (p. 203). This domain represents teacher knowledge of the materials available for teaching specific subjects and the reasons for or against choosing these tools in particular circumstances (Yerrick & Johnson, 2011).

PCK, at the convergence of these knowledge domains, encompasses the specialized expertise from which expert teachers draw to make their daily classroom decisions. Included in this dimension are topic-specific instructional strategies, understanding of student preexisting knowledge and misconceptions, underlying purposes for teaching specific content, effective representations of ideas, along with important illustrations, demonstrations, and analogies related to the expert teaching of content. PCK encompasses knowing what makes topics easier or more difficult to learn and comprehend; since each classroom context will vary greatly in each of these previously mentioned factors, teachers need a multitude of different forms of representation (Shulman, 2004).

Since its inception, PCK has expanded educational research as it has been applied to a wide variety of contexts and topics like educational technology (Koehler & Mishra, 2014) and in applying innovative frameworks like SSI (Sadler, Friedrichsen, & Zangori, 2019; Lee, 2016). As with other areas of teaching, implementing innovative pedagogies requires teachers to draw on specific knowledge. PCK for SSIs involves a student-centered approach and an understanding of multi-disciplinary content that often has unresolved answers (Varma 2024). Zeidler et al. (2011) noted that the implementation of a "novel pedagogy" (p. 277) such as SSI will challenge classroom norms, necessitating "fundamental and deep structural changes" (p. 278) such as establishing new relationships between students and teachers as co-creators of knowledge which can be somewhat uncomfortable for all (pp. 277-278). Most teacher preparation programs do not prepare teachers to teach with strategies like SSI (Lazarowitz & Bloch, 2005). Kane and Staiger's (2012) study of over 1,330 U.S. teachers found a majority of the teachers were not teaching for embedding "critical and reflective on practice" (p. 27) and require professional development (PD) that would "emphasize practices that will turn students into critical thinkers and problem solvers" (Gulamhussein, 2013, p.3). By studying and understanding teachers' PCK, we are better able to design and tailor professional development programs to help teachers select SSI contexts that are personally relevant to students (Saunders & Rennie, 2013) and develop curriculum and assessments based on students' ability to engage in argumentation anchored on their scientific knowledge and personal beliefs (Dolan, Nicholas, & Zeidler, 2009). Moreover, we are better able to understand their successes and challenges in designing and planning lessons that exhibit their PCK of instructional strategies and ability to make appropriate choices about teaching and learning strategies in SSI (Magnusson et al., 1999).

SSIs simultaneously require knowledge of the curricula for multiple science and non-science disciplines which alone is challenging (Witz & Lee, 2009), and teachers must be able to see where and how the SSI will fit at grade level (Lee, 2022). In order to conceptualize, plan, implement, and evaluate the teaching of SSI, teachers must develop PCK specific to this domain, which is separate from and in addition to their PCK for science teaching (Macalalag, Mınken, & Varma, 2023). The teachers' PCK of teaching orientation and instructional strategies guide them as they conceptualize and implement the education of SSI in their classrooms (Magnusson et al., 1999). Teaching orientation and instructional strategies are strongly connected to other components of PCK such as assessments, curriculum, learning context, and students' learning of SSI (Chang & Park, 2020). When teaching SSI, educators must not only focus on the main concepts but also consider factors such as students' previous knowledge, interests, cultural backgrounds, and past learning experiences as they incorporate real-world contexts or issues into their lessons (Zeidler, 2014). Understanding students' backgrounds becomes crucial when selecting SSI cases to ensure they align with students' lives and are personally meaningful to them (Saunders & Rennie, 2013; Yerrick & Johnson, 2011). Moreover, a teacher of SSI must be able to create a conducive classroom environment for student-centered learning and select appropriate teaching methods to allow students to explore and explain the underlying scientific phenomena, engage in scientific modeling, employ reflective skepticism, compare and contrast multiple perspectives, and elucidate their own position or solution (Sadler et al., 2019). This type of student-centered teaching is challenging. The teacher must engage students in research debates, discussions, and value-driven scientific argumentation with social, political, and ethical connections, but they need help with such argumentation (Albe, 2008; Ekborg et al., 2013; Saunders & Rennie, 2013; Tidemand & Nielsen, 2017; Zohar & Nemet, 2002). Since SSIs often draw from current events unfolding in real-time, teachers need skills in vetting and integrating diverse sources of information as relevant teaching materials may not preexist but instead are being generated in real-time. The teacher must help students glean credible evidence from multiple sources other than textbooks to form a complete picture drawing upon their orientation to teaching SSI, knowledge of instructional strategies, and knowledge of cutting-edge science and technology (Lee, 2022). As teachers assess students' engagement in SSI, they gain a sense of students' understanding and challenges and use this knowledge to plan strategies to support students in their learning. The research of Bayram Jacobs et al. (2019) suggests that strong development of PCK for SSI includes, "strong interconnections between PCK components, understanding of students' difficulties in SSI learning, suggesting appropriate instructional strategies, and focusing equally on science content and SSI skills" (p. 1225).

Teachers can develop their own PCK by adopting an inquiry stance toward instructional practice, which entails critical reflection and collaboration (Cochran Smith & Lytle, 1999). Teachers can do this through professional learning activities, such as planning and designing lessons. By adopting this stance teachers will "make problematic their own knowledge and practice as well as the knowledge and practice of others" (p. 273). This incorporation of the discursive elements of SSI (e.g. questioning data from multiple sources) and effective implementation of lessons are pivotal to SSI teaching (Sadler et al., 2019; Minken et al., 2021). Such substantive change is difficult to enact and maintain (Yerrick, Parke, & Nugent, 1997), yet it can facilitated and supported for both preservice and in service teachers through directed and well-structured coursework and professional development (Macalalag, Johnson, & Lai, 2017). It is with this in mind that the USTRIVE professional development model was developed.

USTRIVE Professional Development Structure

The overarching USTRIVE project goal was to transform STEM education to provide "meaningful opportunities for students to become *empowered, STEM-literate citizens* capable of advocating for change" (Macalalag, 2021). Each year of participation in the USTRIVE project entailed eight days intensive professional development at the USTRIVE summer institute (six hours per day) followed by three professional learning workshops (three hours each), interspersed with two field trip opportunities (three hours each), six professional learning community (PLC) meetings (three hours each), and an end of year conference (six hours) at minimum. During workshops and the summer institute, experts provided strategies on how to develop modeling, reasoning, social justice in STEM, and scientific argumentation skills in students

Project teachers developed SSI units of study for implementation in their classrooms using the USTRIVE framework as a guide and sTc lens for social justice as presented in the USTRIVE PD. Johnson et al., (2022) found that teachers who had the opportunity to experience SSIs firsthand as a student were more likely "to facilitate and maintain integration of SSI" (p. 8), thus summer institute sessions were designed to provide teachers with firsthand experience as students, learning SSI lessons modeled by institute facilitators. Examples of model SSI lessons included global warming and urban flooding, local speed limits surrounding schools, gerrymandering, and global population and resource use to name a few. These sessions were generally followed by discussion and guided reflection of the experience, what aspects of the USTRIVE rubric were evident, what might have been lacking, and how the presented aspects might fit into participants' curriculum. Finally, teachers were provided time to work on unit development, incorporating the aspects of the USTRIVE framework discussed into their developing unit with the assistance and guidance of facilitators, coaches, and peers from both cohorts of participating teachers. Additionally, guest speakers provided additional information regarding social justice, educational theory underlying the USTRIVE framework, and establishing connections to local science-based resources that could be leveraged in SSI unit plans.

Lasting change and effective implementation of novel pedagogies requires not just effective presentation of these novel ideas, but longitudinal support for teachers (Yerrick, Parke, & Nugent, 1997). Thus workshops, field trips, classroom coaching, PLC meetings, and friendly classroom visits (as differentiated from research visits) were provided throughout the two years of USTRIVE participation to provide support and guidance in unit development and classroom implementation. Teachers could request funds supplement costs for classroom materials required for unit implementation.

Significant research on the effectiveness of the USTRIVE PD has been and continues to be done with regards to participating teachers and their students. Data gathered includes baseline demographic data, initial unit storylines, three separate unit draft submissions following the two-week institute, at the end of year one, and at the completion of the program, summer institute field notes and recordings, classroom observations (research visits), student artifacts, post observation teacher interviews, and end of year teacher interviews. Some of the key findings and future directions of project research are presented below.

Research Findings

Teacher Research Findings

Initial research findings from the first three years of the USTRIVE project have shown that directed professional development workshops resulted in positive shifts among the teachers' approaches to instruction in regard to integration of SSI content into STEM lessons (Johnson et al., 2022b; Johnson et al., 2024; Macalalag et al., In Review; Minken et al., 2021; Varma, 2024). Teachers demonstrated an increase in confidence and an increase in capability while embedding real-world STEM-based issues into their lessons, which aligns with the goal of the professional development program. In a case study involving two participant teachers, one teaching math and one science, comparisons were made between teachers' initial conceptions of and practices in SSI and social justice in STEM to their final unit submissions (Johnson et al., 2022b). Authors found that despite past challenges with incorporating debatable, real-world issues, participants exhibited notable growth in the ability to implement aspects of SSI into lessons to engage students in discussions and investigations in the classroom. Focus group feedback, collected by external evaluators after teachers participated in PD workshops through the USTRIVE project, revealed both success in the efforts to support teachers' incorporation of SSI into their lessons and an increase in teachers' knowledge of SSI topics as a result of the PD workshops (Macalalag et al., In Review).

In comparing end of year interviews following program participation for four teachers, researchers found that teachers recognized that their own learning was central to effectively designing and implementing SSI instruction using the USTRIVE framework and teachers' successes in the program were intertwined with developing an awareness of their own learning needs (Johnson et al., 2024). Across the interviews, teachers described themselves as "novices" in SSI implementation yet maintained a positive perspective on their own capacity to learn and improve. In general, project research has shown that participating teachers felt better equipped for the implementation of engaging lessons and documented growth in their capacity to create debatable questions with respect to their unit topics following participation in the program (Johnson et al., 2022b; Johnson et al., 2024; Macalalag et al., In Review; Minken et al., 2021; Varma, 2024).

In addition to improved confidence in effectively implementing novel pedagogies, teachers were also found to exhibit improved cultural awareness and sensitivity through their integration of SSI into STEM lessons (Macalalag et al., In Review; Macalalag, Johnson, & Lai, 2020; Macalalag, Johnson, & Lai, 2017). In exploring submissions from 21 participating teachers, including samples of student artifacts to exemplify students' learning of SSI and stance on social justice, researchers found that participant teachers were better able to implement pedagogies to engage students on social justice particularly in making connections to real-world experiences, developing a community projects, examining social injustice in their lives, and developing an agency to influence and make changes in their lives and communities (Macalalag et al., In Review). By incorporating these diverse perspectives and authentic learning experiences, teachers promote more inclusive classroom environments that acknowledge the societal and cultural contexts of scientific issues (Johnson et al, 2022c). In exploring growth in PCK for the 13 teachers from the first cohort completing the USTRIVE program, researchers found that teachers displayed growth in their ability to incorporate the various components of the instructional framework for SSI introduced in the PD into their teaching, leading to enhanced student engagement through the connection of content to real-world issues outside of the classroom (Johnson, Mathers, Marco Bujosa, & Ialacci, 2024). Teachers in this study also highlighted the benefits of this approach on their students' learning of more traditional content, engaging in the content in deeper ways than with traditional instruction.

Research has also revealed various challenges encountered by participating teachers. In particular, the process of integrating discursive elements of SSI, such as reflective skepticism and consideration of multiple perspectives, proved challenging (Ialacci & Johnson, 2023; Minken et al., 2021; Mathers & Marco Bujosa, 2022; Johnson et al., 2022b). This may stem from a lack of specific training or resources focused on fostering critical thinking and dialogue within SSI discussions. As documented in the study conducted by Minken et al. (2021), only 14% of participant teachers exhibited statements or questions with a discursive nature during the 3rd iteration of their lesson plans with small overall growth seen for the two discursive elements of SSI. Similarly, Ialacci and Johnson (2023) found units from cohort one teachers scored notably lower in terms of discursive aspects within the USTRIVE, particularly in terms of reflective scientific skepticism. Teachers who scored higher on this criteria tended to ask students to question the authors of learning materials, compare disadvantaged or advantaged populations with respect to the SSI, and encouraged questioning the methodology and purpose for obtaining information, while the majority of teachers (89%) failed to include the element employing reflective skepticism, which suggests a lack of emphasis or attention by teachers on this SSI element during the lesson planning process (Minken et al. 2021).

Johnson, Mathers, and Marco Bujosa (2023) found that the discursive domain, while improved from cohort one, remained the weakest domain for both years for cohort two teachers as well. In a follow up study, rubric ratings were calculated for the four dimensions of the USTRIVE framework rubric (Appendix 1). The discursive domain had scores of M=0.96 and M=1.85 with standard deviations of 0.83 and 0.59 respectively, the weakest of the four for both years, however showing notable growth in the discursive domain between years one and two (Johnson et al., 2024). Teachers also struggled with barriers to implementation, including time constraints, limited support from school administration, and uncertainties about curricular integration (Macalalag, Minken, Feighan, Richardson, Marte, Ialacci, Van Meter, Sproul, & Kaufmann, In Review; Marco Bujosa, Mathers Lowery, Johnson, & Araco, 2023). Addressing these barriers may require systemic changes at the school or even the district level to provide adequate resources and support for SSI implementation. Johnson, Mathers, Marco Bujosa, and Ialacci (2024) also reported that participating teachers struggled in integrating the SSI and STEM content in their units of study, particularly in the first year when teachers noted that, while they developed a unit focused on SSI, their instruction was not cohesive or integrated, resulting in a disjointed learning experience in which students were exposed to SSI instruction and more traditional STEM content instruction intermittently, resulting in inconsistency within units. The teachers themselves felt that integrating SSI into STEM lessons was a challenge and had difficulty connecting issues to content.

These findings have important implications for teacher education and professional development in both demonstrating the potential to influence on both practice in and beliefs towards SSI integration in STEM classrooms. In the more immediate term however, these findings have guided the growth and development of the USTRIVE project to best meet the needs of participant teachers.

Student Research Findings

While the bulk of the research from the USTRIVE project has focused on the USTRIVE teachers and professional development, more recent studies have illuminated impacts of USTRIVE practice on students in participating classrooms. Several studies have shown that students in USTRIVE classrooms demonstrated heightened interest and a sense of ownership in their learning when engaging with Socio-Scientific Issues (SSI) (Minken, Macalalag, & Richardson, 2020; Marco Bujosa et al., 2023). In their case study exploring the ways in which teachers' thinking and intention of incorporating Socioscientific Issues (SSI) into their lesson plans change after participating in professional development, Minken, Macalalag, and Richardson (2020) noted the student benefits of increased interest in topics, improved student agency for learning, and improved problem solving strategies for SSI.

Marco Bujosa, Mathers Lowery, Johnson, and Araco (2023) found that teachers reported improved student engagement, both in terms of both ownership of their STEM learning and improved participation in lessons, with the integration of SSI into their STEM curriculum. This was further explored in a follow up study (Marco Bujosa, Mathers, & Johnson, In Review) in which the researchers identified two categories of participants within the group, *Boundary-Crossers* seeking to connect the curriculum to the real world, and *Traditionalists*, who sought to enhance student engagement and motivation through an alternative pedagogical framework. These categories were largely dependent on the teachers' backgrounds and influenced how those teachers defined engagement. While *traditionalists* viewed engagement in terms of active participation in the STEM lessons, *Boundary-Crossers* saw student engagement extending to include participation in the development and implementation of the SSI lessons and continued engagement in the content outside of the classroom. In each study, the authentic nature of the SSI allowed students to connect their learning to real-world contexts, fostering a deeper level of engagement.

Beyond engagement, teachers also reported that students developed critical thinking and problem-solving abilities through SSI lessons beyond what they had observed in traditional lesson delivery (Macalalag et al., 2023; Macalalag, Johnson, & Lai, 2017). They were challenged to analyze complex issues, consider multiple perspectives, and brainstorm solutions, which contributed to the overall learning outcomes. Macalalag, Kaufmann, Van Meter, Ricketts, Liao, and Ialacci (In Review) found that SSI lessons from USTRIVE units promoted interdisciplinary learning, critical thinking, and informed decision-making among students, highlighting the value of integrating SSI in science education to engage students with social justice. Through engaging with authentic, real-world problems, students developed critical thinking skills and deepened their understanding of scientific phenomena within a meaningful context. Findings from that study suggest that students successfully learned components of SSI through inclusion of authentic activities to engage them in inquiry-based, hands-on,and minds-on learning connected to students' lived experience.

Macalalag, Johnson, Minken, Mathers Lowery, Liao, and Marte (2023) found that *authentic activity* was the one component of the USTRIVE rubric included in the majority of the unit plan storylines immediately following participation in the two-week summer institute demonstrating the central role this component played in the USTRIVE planning process from the very beginning of participation. USTRIVE research supports the idea that authentic activities and learning experiences help students understand complex issues of social justice by using information and evidence from many disciplines that are aligned in meaningful ways to students' personal experiences (Lesnefsky et al., 2023). While studying SSIs USTRIVE findings showed that students considered scientific underpinnings and ethical dilemmas surrounding issues while studying interconnected systems and comparing stakeholders' perspectives in lessons promoting student reflection and inspiring change through social justice projects (Macalalag et al., In Review). Students in USTRIVE classrooms showed critical thinking using reflective skepticism and collaborative learning through dialogic conversation by building on each other's ideas.

Despite the benefits, like their teachers, students encountered difficulties with certain aspects of the SSI lessons. Specifically, some struggled in articulating their stances on SSI and critically evaluating information sources. This suggests a need for further support and guidance in developing students' argumentation and information literacy skills. Macalalag, Kaufmann, Van Meter, Ricketts, Liao, and Ialacci (In Review) found that teachers reported that elucidating one's position/solution was indicated by six teachers as the most challenging component for students. Students faced challenges in comprehending the interconnectedness of various social, political, economic, and environmental factors within SSI (Johnson et al., 2022b; Macalalag et al., In Review). Providing scaffolding and explicit instruction in system thinking could help students grasp these complex relationships more effectively. Exploration and explanation of underlying scientific phenomena and exploration of SSI were also indicated as challenging components for students (Macalalag et al., In Review). One teacher in this study reported that exploring relevant socio-scientific issues through math and science was difficult for his class, which is consistent with other findings regarding teacher struggles in integrating SSI and STEM content. Finally, reflexivity was a challenge reported in that some students struggled to consider how the socioeconomic status of others affects what they consider important to learn (Ricketts, Johnson, & Macalalag, 2024; Macalalag et al., In Review), a key point in taking multiple perspectives of SSI stakeholders. Teachers were able to address and overcome many these challenges through scaffolded SSI integration in which they guided students in how to engage in SSI (Marco Bujosa et al., 2023) and through iterative integration of SSI lessons in which student participation moved from guided to more open throughout the school year (Fedell & Johnson, In Review).

Overarching Themes

As discussed above, a number of consistent themes have emerged from research from the USTRIVE project up to this point. In terms of teacher success PD workshops have been shown to lead to improvement in SSI implementation (Macalalag, Johnson, & Mathers Lowery, 2022; Ialacci & Johnson, 2022) and shifts in teacher beliefs and attitudes towards SSI (Minken et al., 2024; Macalalag et al., In Review). Further participation in the USTRIVE program and subsequent SSI implementation into classrooms has been shown to lead to increased cultural awareness for teachers and a more acclimated classroom environment (Johnson, 2023; Macalalag, Johnson, & Lai, 2017). Research has also revealed specific challenges participating teachers face in both PD participation and classroom implementation. These include struggles to implement discursive elements of the USTRIVE framework into SSI lessons (Johnson et al., 2024; Ialacci & Johnson, 2023; Marco Bujosa et al., 2023), to overcome curricular and contextual barriers to SSI implementation (Macalalag et al., In Review; Marco Bujosa, et al., 2023), and to connect SSI problems to STEM content (Johnson et al., 2024).

Emerging research on the impact of the USTRIVE project on students in participating teachers' classrooms has similarly revealed various successes and challenges. SSI lessons have been shown to lead to increased student ownership of STEM content, student agency, and interest when engaging with SSI (Macalalag et al., 2023; Mathers & Johnson, 2024; Marco Bujosa, Mathers Lowery, Johnson, & Araco, 2023). Enhanced problem solving and critical thinking among students is also evident (Macalalag et al., 2023; Varma, 2024; Minken, Macalalag, & Richardson, 2020). Yet, students tended to struggle to articulate their stances on SSI, to evaluate sources of information, and to comprehend the interconnectedness of systems involved in SSIs (Macalalag et al., In Review; Johnson et al., 2022b; Macalalag et al., In Review).

These various findings have guided the continued development of the USTRIVE project. All of the research conducted from the USTRIVE project has been and continues to be framed by the project research questions listed above. As such, it is helpful to situate the findings we have described in terms of these questions.

(1) In what ways, if any, do program activities support in developing teachers' PCK in instructional strategies with emphasis on the three elements of SSI: scientific, social, and discursive?

As described above, positive shifts among the teachers' approaches to instruction are evident throughout the USTRIVE research in regard to integration of SSI content into STEM lessons (Johnson et al., 2022b; Johnson et al., 2024; Macalalag et al., In Review; Minken et al., 2021; Varma, 2024). Analysis of submitted units of study at the end of year one of the program identified areas of the

USTRIVE rubric where teachers had the most potential for growth, guiding revision of the PD to target those areas and provide additional support to teachers (Johnson et al., 2024). The second year in the program included 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*. Quantitative data from the second cohort of teachers indicated increases in teachers' knowledge and understanding of SSI issues and comfortability with application (Macalalag et al., In Review). Teachers changed by considering different stakeholders and including their cultures, having resources and lessons to teach social justice, knowing and educating oneself on current issues, and seeing injustices in their community and institutions.

(2) How does the teachers' PCK of students' understanding of SSI impact civic engagement as social agents of change?

In addition to making meaningful connections to facilitate student engagement with SSI context, another success in the development of PCK is that it increases teachers' and, as a result, students' knowledge and understanding of STEM content (Johnson et al., 2020). Mathers, Johnson, Kaufman, Sinni, Louis, & Henneman, (In Review) identified several themes across successful units in cohort two teachers in terms of fostering student agency through SSI integration, the cross curricular and collaborative nature of SSI lessons, extension of lessons beyond classroom walls, authenticity in planning and lesson content, and extension activities that shift lessons to more student driven action. Macalalag, Johnson, Minken, Mathers Lowery, Liao, & Marte (2023) indicated that, through participating in SSI activities first-hand, USTRIVE teachers were able to experience SSI as both learners and reflective instructors, thus, developing their PCK allowing them to make meaningful connections to facilitate student engagement with SSI in context. The development of PCK in this regard helps teachers make connections to students' experience and increasing teachers' and, as a result, students' knowledge and understanding of STEM content. In another study (Macalalag et al., In Review) cohort two teachers provided specific examples of how their knowledge of social justice, and thus their PCK towards facilitating civic engagement evolved. The most commonly cited examples include; considering different stakeholders and their culture, having resources and lessons to teach social justice, knowing and educating oneself on current issues, and seeing injustices in my community and institution. Findings from that study suggest that teachers' PCK included orientation toward teaching social justice after attending our PD.

(3) In what ways, if any, do teachers' dispositions change towards teaching with sTc?

Shifts in teachers' dispositions towards teaching with SSI and sTc are evident throughout the existing USTRIVE literature. Numerous studies have shown positive shifts among the teachers' approaches to instruction in regard to integration of SSI content into STEM lessons using the USTRIVE SSI/sTc framework (Johnson et al., 2022b; Johnson et al., 2024; Macalalag et al., In Review; Minken et al., 2021; Varma, 2024). Participating teachers in each of the first three cohorts have demonstrated an increase in confidence and an increase in capability toward embedding real-world STEM-based issues into their lessons, which aligns with the goal of the USTRIVE professional development program (Johnson et al., 2022b; Johnson et al., 2024; Macalalag et al., In Review; Minken et al., 2021; Varma, 2024). It will be interesting to explore in future research how these shifts, and their potential impact on classroom practice, persist once participation in the program ends.

(4) What factors support and inhibit teacher leadership to promote SSI/sTc?

While the leadership aspects of the USTRIVE program have not been fully explored, initial research has yielded promising results (Macalalag et al., 2023). Specifically, the end of year conference, conference travel funding, PLC meetings, and academic coaching aspects embedded into USTRIVE participation have shown strong potential for developing participant teachers into teacher-leaders. This is an area of focus for future project research, specifically focusing on what aspects are effective, in what ways they are effective, and how this impacts both program teachers and their non-participant colleagues in terms of SSI integration.

(5) How do justice-centered STEM lessons help students to develop elements of SSI (e.g. moral and ethical reasoning, scientific skepticism, STEM inquiry/modeling, SSI

discourse/argumentation)?

Again, it is important to note that the bulk of the research that has emerged from the USTRIVE project has focused on participant teachers and the impact of USTRIVE professional development practices, however, research focusing on the impact of USTRIVE practices on students in participant teachers' classrooms continues to develop. In terms of aspects of SSI that students are learning in participating classrooms, Macalalag, Kaufmann, Van Meter, Ricketts, Liao, & Ialacci (In Review) analyzed student artifacts provided by teachers and identified SSI aspects that students seemed to thrive with and those that were more challenging. The most success was evident in; Elucidate own position/solution (n=12), exploring and explaining the underlying scientific phenomena and/or concepts in mathematics (n=11), exploration of SSI (n=10), and considering issue system dynamics (n=8). Interestingly, elucidating one's position/solution was reported by six teachers in that study as the most challenging component for students, followed by employing scientific skepticism (n=5), indicating that elucidating one's position/solution was difficult, yet students were able to find success in doing so following their participation in the USTRIVE SSI unit. This same study also analyzed teacher provided examples of social justice (sTc) aspects embedded into the USTRIVE framework that exemplify their students' stance on social justice. In the 21 responses provided, 10 mentioned metacognition, six mentioned reflexivity, and three each mentioned authentic activity and dialogic conversation. These findings indicate promising development among students in terms of SSI/sTc components within the USTRIVE framework, however additional research is needed and continues to be done in this area.

(6) In what ways, if any, do students exhibit civic engagement as social agents of change through SSI?

This is an area of current and ongoing research. Mathers, Johnson, Kaufman, Sinni, Louis, and Henneman (In Review) are currently exploring how participant USTRIVE teachers foster authentic, active engagement and student agency in their STEM classroom following participation in the program. Varma (2024), listed the following teacher practices and aspects of SSI/sTc for promoting student agency; Providing room for mistakes, reflection, and correction, being cognizant of potential problem-solving pathways, evaluating student explanations for consistency with evidence, being familiar with strategies that promote discussion and group work, helping normalize classroom discussions and peer evaluations, exposing power structures, showing how power can be challenged, providing choice in content, process, assessment, and level of engagement, incorporating student backgrounds and ideas into classwork, disseminating information, and encouraging discourse from evidence from a variety of sources. It will be illuminating to see how future studies reveal the ways in which SSI/sTc lessons from USTRIVE units impact students in developing them as social agents of change.

Conclusions

The USTRIVE project has several primary goals outlined to describe the project and focus its efforts in line with its genesis. The first goal states that the project is meant to facilitate development, implementation, and reflection on units of study that combine socio-scientific issues (SSI) and socio-transformative constructivism (sTc) frameworks. Success in this regard in the project thus far has been demonstrated based on the effectiveness of the professional development programs in helping teachers implement the USTRIVE framework (Appendix 1), which combines SSI and sTc frameworks. sTc has shown to be a natural complement to the SSI framework, providing a powerful lens for viewing the social justice aspects of teachers' units of study. The second goal is to cultivate pedagogical content knowledge (PCK) in teaching orientation and instructional strategies with regard to SSI/sTc. The success of this goal can be seen exemplified in teachers' pedagogical and ideological shifts as they adjust their style of teaching to incorporate new models and practices. The third goal is oriented for the people involved in the project to acquire instructional design capabilities to develop and implement lesson plans, assessments, classroom resources, and reflections, within units of study, that emphasize the development, testing and revising of STEM modeling and the discursive nature of SSI (i.e., self-reflection and scientific skepticism). While the USTRIVE project has had great success in helping implement these new methods of instruction, there is still room for development, especially in the discursive elements. The fourth and final goal of the USTRIVE project is to foster the scientific literacy of students through development of cultural competence and with a sociopolitical consciousness instructional lens. The USTRIVE project is meant to expand the body of literature that exists in the areas described and, upon review of the existing literature, the research that has been done in relation to the project is well situated within the landscape of the body of literature to expand knowledge of PD focused on SSI and social justice, development of teacher PCK for SSI and sTc, fostering the integration of novel pedagogies into STEM curriculum, and development of functional scientific literacy among STEM students.

Declaration of Author Contribution

The first author contributed 40%, the second, third, and fourth authors 20% each to the study.

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Conflict of Interest Statement

There are no conflicts of interest with any institution or individual related to this study. Additionally, there are no conflicts of interest among the authors.

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Appendix 1: USTRIVE Framework and 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" (Zeidler & Kahn, 2014, p. 31).
2) Consider issue system dynamics Ask students to consider a system associated with their SSI. The system may include interactions of humans with nature as well as social components such as political, cultural, economic, ethical, health, nature, equity, and religious considerations.
3) Compare and contrast multiple perspectives Ask students to obtain and evaluate information from a range of stakeholders such as environmental activists, politicians, political groups, researchers, scientists, religious organizations, and media.
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 (Sadler et al., 2019).
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, A.J. & Morrison, D., 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.

Excerpts from Unit Planning Rubric / Guide

Directions: Provide qualitative evidence (descriptions, text from teacher units) to justify and support the code. Include this evidence and report it with the codes.

NOTE: Failing to meet the minimum criteria for a Level 1 code results in a code of Level 0

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**

<table>
<tr><td>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.</td><td>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.</td><td>The purpose of learning is framed in learning content knowledge and skills in science and mathematics.</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td>Level 3</td><td>Level 2</td><td>Level 1</td></tr>
<tr><td>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.</td><td>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.</td><td>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.</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td>Level 3</td><td>Level 2</td><td>Level 1</td></tr>
</table>

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).

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 context If 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	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.

more ownership over their own learning.		