We Strive: Enhancing Implementation of Socioscientific Issues in STEM Classrooms Through Professional Development

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Abstract: This study explores the experiences of two teachers participating in professional development workshops focused on supporting implementation of SocioScientific Issues (SSI) and aspects of social justice into STEM classrooms. SSI are ill-defined problems, with a basis in science, but necessarily include moral and ethical decisions that cannot be resolved through science alone. These debatable issues can enhance learning of STEM by engaging students in real-world and authentic problems. The *USTRIVE project* was developed to foster STEM learning through integrated professional development workshops and the development of professional learning communities to support teachers in the use of SSI and incorporation of aspects of social justice in their STEM classrooms. Two research questions were investigated: (a) To what extent did teachers implement SSI into their lesson planning during the project and (b) In what ways did teachers' designed lessons change from the beginning of the workshop?

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Introduction

Current education reform movements in science and mathematics advocate for teaching science, technology, engineering, and mathematics (STEM) disciplines by solving real-world problems (National Research Council [NRC], 2013; Sadler et al., 2007). Incorporation of socioscientific issues (SSI) into STEM classrooms can provide meaningful contexts for students to learn concepts and practices in these disciplines (Zeidler et al., 2005) and powerful avenues for engaging traditionally marginalized student groups in STEM content (Johnson et al., 2022A; Johnson et al. 2022B). Yet common STEM teaching practices rarely allow students, especially low-income students of color (Marco-Bujosa et al., 2020), to connect STEM lessons with their own lives (Zeidler, 2016). While this may not be a result of purposeful resistance to teaching for diversity, teachers may lack the awareness, support, confidence, knowledge, or skills to implement socially relevant curriculum and culturally responsive strategies (Rodriguez, 2005). Moreover, teachers may be hesitant or struggle with some fundamental components of the SSI framework such as inquiry, problem-based learning, argumentation, and authenticity (Johnson et al., 2020). Fortunately, directed coursework and professional development can provide prospective teachers with the knowledge, resources, and experience to develop the necessary skills for effective SSI implementation (Johnson et al., 2020).

The SSI framework consists of debatable issues that can enhance learning of STEM concepts as students engage in real-world and authentic problems (Zeidler, 2014). SSIs are ill-defined problems that have their basis in science, but necessarily include moral and ethical decisions that cannot be resolved through science alone (Ratcliffe & Grace, 2003). As such, SSI can provide meaningful and relevant contexts for students to learn science concepts and practices across STEM fields (Zeidler et al., 2005). Students engage in STEM content to address moral and ethical problems through reflection on their personal experiences, prior knowledge, and cultural background, promoting students' STEM learning and scientific skill development (Ziedler, 2014), especially when engaging in those issues that have a disproportionate, negative impact on their lives. SSI implementation can provide avenues for teachers to enhance their students' scientific knowledge and literacy skills, such as evidence-based reasoning, consideration of multiple perspectives, and reflective scientific skepticism (Minken et al., 2021). However, most teachers are unfamiliar with SSI and require coursework or professional development in order to learn how to effectively plan instructional activities by engaging their students on its components (Macalalag et al., 2017).

The USTRIVE Project (*Understanding STEM Teaching Through Integrated Contexts in Everyday Life),* funded through a large National Science Foundation Discovery Research in K-12 federal grant, was developed to foster STEM learning for close to 3,000 students in grades 6–12 over four years through integrated professional development workshops and the development of professional learning communities focused on supporting teachers in the use of SSI and incorporation of aspects of social justice in their STEM classrooms.

In implementing SSI in the classroom and addressing controversial issues, teachers must be knowledgeable in several key areas within the SSI framework, including logical reasoning, recognizing fallacious reasoning, comparing, and contrasting multiple perspectives, engaging in scientific modeling, and more (Zeidler et al., 2002). Successful implementation of SSIs strongly depends on the scientific content knowledge of the teacher, and the pedagogical knowledge that they bring to bear. By developing understandings of SSIs, particularly those involving local problems, and linking them to effective pedagogical practices, students are given opportunities to analyze and resolve situations that relate directly to them and their lives (Hernández-Ramos, 2021). Shulman (1987) defined the intersection of pedagogical knowledge and content knowledge, situated within teachers' knowledge of the learning context, as Pedagogical Content Knowledge (PCK), a powerful framework for understanding teacher growth and development. As such, PCK was chosen as the conceptual framework for the current study. Goals of the USTRIVE project included (1) development of teacher PCK to support their capacity to develop, implement and reflect on instructional units that use SSI to promote students' scientific literacy, cultural competence, and sociopolitical consciousness; (2) development of teacher dispositions toward social justice and SSI; (3) fostering of teacher PCK to develop, write and implement units of study with lesson plans, assessments, and classroom resources.

For the current study, the PCK framework was applied with a qualitative case study methodology to analyze initial findings regarding teacher development after the first semester of implementation of the USTRIVE project. The authors of this study are all researchers on the USTRIVE project who worked on the design and implementation of the project professional development workshops. The first and second authors were co-principal investigators for the USTRIVE grant. The following research questions guided this study: (a) To what extent did teachers implement SSI and its components in lesson plans designed through USTRIVE workshops and (b) In what ways did teacher lessons and planning change from the beginning of the workshop?

Conceptual Framework

According to Shulman (1987), PCK is the knowledge teachers require that is essential for them to effectively plan and implement teaching methods to help learners of various levels and backgrounds learn concepts and skills during instruction. PCK exists at the intersection of areas of teacher knowledge that facilitate effective pedagogical decision making. It is a special amalgamation of knowledge and teaching practices that directs teachers' actions while planning and implementing their lessons (Shulman, 1987). PCK in general, and PCK for teaching SSI, includes several subdomains. It includes knowledge about the content and curriculum, such as teachers' awareness of the curriculum goals, objectives, and the vertical alignment and progressions of students' learning (Magnusson *et al.*, 1999; Bayram-Jacobs *et al.*, 2019). PCK for teaching SSI also requires instructional strategies to craft and engage students in debatable issues or questions, to support students in their inquiry experiences, and to develop their reflective scientific skepticism as they compare and contrast multiple perspectives (Johnson et al., 2020). A teacher's knowledge of instructional strategies includes the teacher's ability to make appropriate choices about pedagogical strategies available in incorporating SSI (Magnusson et al., 1999). This is closely intertwined with the teacher's knowledge of student understanding and assessment. A teacher of SSI must have the versatility to incorporate a variety of teaching strategies that allow students to explore the underlying scientific phenomena, employ reflective skepticism, engage in scientific modeling, compare multiple perspectives, and elucidate their own position, all of which are key components of SSI (Sadler et al., 2019). All of this knowledge is situated within a knowledge of the teaching and learning context. Teaching SSI effectively requires understanding the learning contexts in terms of background knowledge of the experiences, culture, and interests of students, while considering issues that are grounded in their community (Johnson et al., 2020).

Methodology

This study employed the PCK framework to guide a qualitative case study methodology to address the stated research questions. Case study research involves the exploration of a bounded "case" or "cases" within clearly defined, real life contexts (Cresswell & Poth, 2016). This methodology allows researchers to delve deeply into complex aspects within the bounded system defined by the selected case (Johnson & Christensen, 2019). According to Cresswell and Poth (2016) cases may be concrete, as in small groups, individuals, or an organization. They may also be more abstract entities like a relationship, a community, or a project. The case for the current study includes two teachers participating in a large-scale U.S. government funded grant that involved weekly workshops focused on integration of SSI into STEM subject areas. Pseudonyms were used for the two participants in this study. At the time of the study, Ms. Rodriguez held a B.S. in Mathematics and a M.A. Secondary Education and Teaching. She had 19 years of teaching experience and was teaching grades 11 and 12 precalculus in a large urban kindergarten through grade 12 school in Philadelphia, PA. The second participant, Ms. Anderson, held a Master's of Education and had been teaching for 22 years. At the time of the study, Ms. Anderson taught 6th grade science in a large urban middle school in Philadelphia. These two participants were selected for the case because they demonstrated sophistication in creating SSI Unit Plans based on the rubric requirements defined by the research team. This allowed for analysis of the differences in improvement from the participants' baseline lesson plans collected early in the workshops to their most recent lessons.

The professional development (PD) program included about 100 hours of the following activities from September 2021 to June 2022: (a) 19 three-hour Tuesday evening workshops, (b) 6 three-hour Professional Learning Community (PLC) sessions, (c) 4 two-hour one-on-one lesson planning meetings and teacher classroom support visits, (d) 2 six-hour Saturday workshops and field trips, and (e) 1 six-hour end-of-year conference. The Tuesday evening workshops focused on introducing teachers to SSI in the context of STEM lessons. Example topics included how to define a socioscientific issue and make it relevant to students; what it means to take multiple perspectives; how to effectively use debates to engage students in SSIs; what it means to be scientifically skeptical; possible topics for debates and contexts for SSI units of study; the ways in which culture influences our individual decisions and indirectly affects our environment and health; how to identify debatable issues from scientific phenomena and develop lessons using debatable issues and scientific phenomena; and how to engage students in STEM modeling in the context of SSI; how to engage students in culturally relevant STEM projects; and how to connect debatable issues to the local community.

The PLCs were developed to provide teachers an extensive professional network, to develop trust among colleagues, and to build deeper content knowledge. Topics focused on the aspects of effective SSI lessons, debatable issues, how dynamic systems can frame a debate, and how stakeholders clarify an issue. Discussions addressed how STEM modeling can foster deep scientific knowledge construction, what the word justice means, and how to collect student data to measure growth.

Classroom support visits provided teachers with guidance as they developed and implemented their units of study and helped grant coaches to monitor teachers' challenges both in the classroom and within the school. They also provided a level of teacher accountability to implement SSI lessons. These visits were intended to increase teachers' confidence as they investigated and implemented new content and practices in their classrooms. Saturday workshops and field trips clearly framed academic and scientific discourse in the classroom and modeled the discursive nature of SSI complemented by discussions of STEM in the community.

The purpose of the end of year conference was to cultivate teacher leadership toward SSI. Participating teachers had the opportunity to present mini-lessons from their units of study. This conference was intended to foster dialogue among teachers, students, school leaders and community members, allow teachers to reflect on learning experiences, provide an avenue for local community involvement, disseminate project work, and celebrate classroom successes.

Case study research is further defined as "a qualitative approach in which the investigator explores a real life, contemporary bounded system (a case) or multiple bounded systems (cases) overtime, through detailed, in-depth data collection involving multiple sources of information" (Cresswell & Poth, 2016, p. 96). Data analyzed for the current study included information from a baseline questionnaire administered at the beginning of the grant experience and lesson plans developed by the participants. Lesson plan data was analyzed using a rubric developed by the research team and provided to participating teachers. Feedback from teacher focus groups conducted by project external evaluators, Public Health Management Corporation (PHMC), Division of Teaching & Learning, Research & Evaluation Group was also used to inform claims. While this data was aggregated from the entire body of project teachers, it provided important contextual information regarding the attitudes and reactions of the group to inform our analysis of our specific case. These data sources were used for triangulation to enhance the reliability and trustworthiness of our findings. Triangulation involves the use of multiple data sources during the analysis of data (Denzin, 2009).

Inductive analysis of baseline questionnaire data, outlined below, provided an initial set of codes that informed the analysis of lesson plan data. Specifically, we wished to understand if teachers were incorporating debatable issues and/or real-world problems into their STEM lessons before beginning our PD program and if after PD workshops on the development of lessons with an SSI focus, teachers felt comfortable creating and implementing these types of lessons. Themes were developed from the initial lesson plan analysis, triangulated across participants and focus group feedback, and compared with lesson plan data to illuminate areas of growth as well as challenges faced by participants.

Baseline Questionnaire Data

During the first Professional Development (PD) workshop, the teachers were asked to describe a lesson they taught that exemplifies ideal STEM instruction and to recount the ways, if any, they engaged and motivated their students to learn STEM with a focus on debatable issues and/or real-world problems. Finally, the teachers expressed any challenges they have encountered in the past when trying to implement a STEM lesson anchored on a debatable issue and/or real-world problem. The baseline questions were chosen to gauge the teachers' perceptions of ideal STEM instruction and to understand what they believed made a STEM lesson exemplary. Second, their answers provided an avenue to get a sense of the teachers' knowledge related to SSI before engaging in the project. Finally, we strived to understand why the teachers may not have attempted or have been unsuccessful in implementing lessons with a focus on debatable issues and/or real-world problems in the past.

For the baseline data, we used an inductive approach to data analysis to allow the data to speak for itself rather than assigning themes derived from the literature. We created a coding guide based on the initial questions asked at the beginning of the workshop, specifically on implementation of STEM lessons and lessons with a debatable and/or real-world issue.

Lesson Plan Data

As part of the professional development workshops from September to December 2021 (3 hours per week, 45 hours total), time was allotted for teachers to develop and write lesson plans by integrating the SSI components in the 5Es framework – e*ngage, explore, explain, elaborate,* and *evaluate* (Bybee et al., 2006). Specifically, as part of *engage*, teachers planned and wrote how they would help their students establish relevance by identifying an SSI issue and by exploring the underlying scientific phenomena that are relevant to their students' lived experiences. In *explore*, they indicated their plan on how to engage students in scientific modeling through development, use, evaluation, and revision of scientific models. In *explain*, teachers wrote how to help their students express new learning by considering issue system dynamics that social, political, economic, ethical, and religious considerations associated with their SSI debate. As part of *elaborate*, teachers wrote a plan to help students apply their prior learning and acquire new learning experiences by asking them to employ reflective skepticism and compare and contrast multiple perspectives as part of SSI. Finally, in *evaluat*e, they wrote how to help their students measure their learning by elucidating their own position or solution at the end of the SSI debate or statement.

The two lesson plans that were submitted by Ms. Rodriguez and Ms. Anderson in December 2021 were coded guided by the SSI framework (Boyatzis, 1998) and the project developed lesson plan rubric (see Appendix A). We used these codes to find themes and analyze the extent to which the teachers incorporated SSI components in their lesson plans and describe ways their lessons changed from the beginning to the midterm point of the first year of the professional development workshops.

Findings

Initially, Ms. Rodriguez described two lessons which she felt exemplified ideal STEM instruction. In a derivatives unit, her students determined the maximum area of a protesting space while considering a six-foot distance between each protestor. In the second lesson she described, Ms. Rodriguez also challenged students to collect data related to the extinction of a subspecies of a rhino. Students identified a regression model to best fit the data, used the model to make predictions, decided if the chosen model was the best fit by providing supportive evidence, and created an alternative model if needed. Ms. Anderson shared an ideal STEM lesson from the Waterworks curriculum called Rain to Drain. Students need to construct a situation out of the materials and explain what is happening to the amount of water used in the experiment and how they can save more water.

Neither teacher had previously taught a STEM lesson with a debatable issue focus; however, Ms. Rodriguez had implemented discussions in the past regarding pollution in which she had students take sides. Both teachers described past challenges with incorporating a debatable issue and/or real-world problem into STEM lessons. Ms. Rodriguez stated that it was a challenge to find real and relevant data to use in her lessons, while Ms. Anderson conveyed her challenges included time, behavior, and the reading levels.

Analysis revealed evident growth in participants' ability to implement specific aspects of SSI into their lessons. Rubric data is presented in Table 1.

Table 1: *Score by SSI Elements; Rubric Data*

	Ms. Anderson (Pseudonym)	**Ms. Rodriguez (Pseudonym)**
A) Identify the Issue	3	3
B-1) Knowledge: Sci. Phenom.	2	3
B-2) PCK: Sci. Phenom.	3	3
C) STEM Modeling	3	3
D) Issue System Dynamics	0	2
E) Reflective Scientific Skepticism	0	0
F) Multiple Perspectives	0	3
G) Elucidate Own Position/Solution	0	1
H) Reflexivity	0	1
I) Authentic Activity	3	3
J) Dialogic Conversation	2	3
K) Metacognition	2	1

The lesson plans developed by Ms. Rodriguez and Ms. Anderson promote real-world and STEM-based issues that are relevant to students' lives and their community. In particular, the SSI debatable questions in Ms. Rodriguez's lessons are, "Should the government regulate housing prices?" and "Should there be a limit on housing prices?" She hoped to engage her students in the following real-world problem: "Property prices are inclining and forcing people to abandon the idea of becoming homeowners, [which] impact homeowners and renters." She continued by explaining that this problem of unfair cost of housing promotes inequality to those who can and can't afford to buy and rent houses. At the end of her lessons, Ms. Rodriguez hopes her students will be able to: (a) "Explain the fundamental concepts of time value of money," (b) "Calculate present and future value of a single and a series of cash flows," and (c) "Apply the concepts and calculations of time value of money in personal financial management." Similar to Ms. Rodriguez, Ms. Anderson's lesson engages students in an SSI and a real-world problem of "whose job is to provide clean water to our community?" According to the description of her lesson, "We assume that we can turn on our faucet in Philadelphia and water that is acceptable for living will exist." She continued by saying that "families rely on bottled water to accomplish daily living," which implicitly suggests possible impact to the environment (use and recycling of plastics) and the added cost of buying them. At the end of her lessons, Ms. Anderson hopes her students will be able to "explain the need, usage, and importance of water as a person, community, and global community."

In addition to identifying an SSI issue, participant teachers presented two different approaches on how to engage their students in exploring the underlying scientific or mathematical phenomenon. Ms. Rodriguez planned to show a short video from MTV Cribs and ask the questions to elicit her students' initial ideas and interests with regards to buying or renting a house. Then, she will ask her students to go to Zillow.com to choose two homes in the region and to analyze the cost of these homes with annual salary per profession and cost of education. Ms. Anderson will use an activity to discuss why water is important and how humans use water. The difference between the two pedagogical approaches is that Ms. Rodriguez plans to elicit her students' initial ideas and dispositions on SSI, while Ms. Anderson plans to use an activity without eliciting her students' prior knowledge or beliefs.

In terms of engaging students in scientific modeling through development, use, evaluation, and revision of scientific models as part of SSI, we found that both lessons describe ways students can participate in discussions and investigations. For instance, Ms. Rodriguez has several questions to guide her students' inquiry: "(a) What is the standard of living in certain areas? (b) What is the median wage in certain areas? (c) Compare crime rates and poverty in those areas? (d) What is the population in Philadelphia and surrounding areas? (e) Is there a correlation between population and standard of living? and (f) How do population and standard of living relate to crime rates/poverty?" On the other hand, Ms. Anderson describes a series of investigations: "Task card 1- Water Usage Chart- How do we use water? Task card 2- Water Descriptive Words- How is water essential (define in your own words what this word means) to life and culture? Task Card 3- Global Awareness Fact Sheet- How do you relate to the facts provided on the Global Awareness Fact Sheet? Task Card 4- Power of Water - an article regarding Tsunamis and Hurricanes - Explain how water behaves?"

Unfortunately, we found that both lessons provided little or no evidence in considering issue system dynamics of social, political, economic, ethical, and religious considerations associated with their SSI debate. For example, in Ms. Rodriguez's lesson, she plans to show a video on the housing crisis in the U.S. and the growing movement to end single family housing zones. She also plans to provide reading material about the housing market over the last 20 years and invite a guest speaker on financing homes. However, it is implicit how her planned activities could promote discussions with regards to social, political and economic aspects of the cost of buying homes. Similarly, Ms. Anderson's plan does not include explicit consideration of system dynamics: "Students will present their findings from the Task card with the class."

In addition to system dynamics, we also found little or no evidence of employing reflective skepticism and comparing multiple perspectives in their lesson plans. Although Ms. Rodriguez's activities will promote problem solving, it is unclear if and how students will question and critique the different information they find or were presented to them. Instead, students were tasked to analyze different variables before answering if they can afford their dream home: "Given three mortgage rates from different banks, they have to calculate the mortgage payments using the future/present value formulas and the total amount paid over 15- and 30- years. They have to consider any student loans, bills, and other debts." On the other hand, she plans to ask her students to do a role play: "Who are the stakeholders in housing prices?" that could potentially promote the examination of multiple perspectives from realtors, buyers, tenants, investors, banks, government, and others. Ms. Anderson plans to ask her students to reflect on "What happens as a result (as an individual, community, society) of actions we take towards water?" Note that this question will examine results from multiple sources, which is different from comparing and contrasting multiple perspectives.

We found that both lessons allowed students to reflect and state their own position or solution at the end of the SSI debate or statement. Specifically, Ms. Rodriguez will ask her students to "make a decision based on evidence; create presentation slides and script for student presentation." While Ms. Anderson will provide an exit ticket question: "how do I show I value water?"

The findings from teacher focus groups feedback, collected by project external evaluators, PHMC, support our findings by demonstrating the success of professional development efforts to support teachers in the use of SSI and the incorporation of aspects of social justice in their STEM classrooms. Teachers' knowledge of SSI/sTc topics increased as a result of the PD workshops offered during the first fifteen weeks of the project. Similarly, teachers felt better equipped to implement engaging lessons using presentations and classroom discussions. Teachers also documented growth in their ability to create debatable questions related to their unit topics. Through the PD workshops and fall field trips, teachers were introduced to hands-on, authentic learning opportunities that serve as a model for the types of activities they can incorporate into their units of study.

Discussion

The following research questions guided this study: (a) To what extent did teachers implement SSI and its components in lesson plans designed through USTRIVE workshops and (b) In what ways did their lessons and planning change from the beginning of the workshop? Findings suggest that although Ms. Rodriguez and Ms. Anderson had science and math contexts in mind in the beginning, neither teacher had attempted to implement an SSI component prior to the PD. Both teachers recounted challenges with incorporating a debatable issue and/or real-world problem into STEM lessons in the past. For example, Ms. Rodriguez stated that it was a challenge to find real and relevant data to use in her lessons, while Ms. Anderson conveyed challenges with time, student behavior, and the reading levels of the students. These initial challenges of our teachers are similar to those challenges experienced by teachers in other projects who start to implement SSI and inquiry-based learning (Zeidler, 2016; Johnson et al., 2020).

Our PD provided teachers with about 100 hours of activities for them to learn SSI and implement them in their classrooms. These PD included Tuesday evening workshops, PLCs, classroom support visits, Saturday field trips, and end-of-year conference from September 2021 to June 2022. After engaging in PD activities focused on SSI, it was found that teachers provided better real-world and SSI contexts in their lessons than in the beginning of the PD workshops. In response to the call of Zeidler (2014) to make STEM learning authentic and relevant, the lesson plans developed by Ms. Rodriguez and Ms. Anderson both promote real-world and STEM-based issues relevant to their students' lives and their community. Moreover, as Rodriguez (2005) argued for socially relevant curriculum and culturally relevant strategies, Ms. Rodriguez aimed to introduce her students to the inequality that those who can and can't afford to buy or rent houses because of the unfair cost of housing. Similarly, Ms. Anderson focused on the importance of freshwater for people, communities, and the world.

Interestingly, teachers presented two different approaches to engage their students in exploring the underlying scientific or mathematical phenomenon. We found that both lessons provided little or no evidence in considering issue system dynamics of social, political, economic, ethical, and religious considerations associated with their SSI debate. They also showed little or no evidence of employing reflective skepticism and comparing multiple perspectives in their lesson plans. These challenges are common to those who are unfamiliar with SSI and who are starting to develop their PCK toward SSI (Zeidler, 2014; Lee, 2016). Finally, we found that both lessons allowed students to reflect and state their own position or solution at the end of the SSI debate.

Conclusion and Recommendations

This study employed the PCK framework to guide a qualitative case study methodology to address our research questions. Our PD program included about 100 hours of workshops, PLC sessions, one-on-one lesson planning meetings and teacher classroom support visits, Saturday workshops and field trips, and an end-of-year conference that supported the development of our teachers' PCK. In particular, the lesson plans developed by Ms. Rodriguez and Ms. Anderson promoted real-world and STEM-based issues that are relevant to their students and community. This suggests that the development of teachers' PCK in teaching SSI requires understanding of the learning contexts that are grounded in background knowledge, experiences, culture, and interests of students, a finding consistent with prior research (Johnson et al., 2020). In addition to SSI contexts, our teachers presented multiple approaches on how to engage their students in exploring the underlying scientific or mathematical phenomenon. They mentioned ways to elicit their students' initial ideas and interests with regards to their chosen SSI context, which indicates the development of the teachers' PCK with regards to content, curriculum, and progressions of students' learning (Bayram-Jacobs et al., 2019). Moreover, we found that both lessons describe ways to engage students in scientific modeling through development, use, evaluation, and revision of models as part of SSI that points to the development of teachers' PCK of instructional strategies in incorporating SSI in lesson plans (Magnusson et al., 1999).

However, similar to previous research that showed teachers' successes and challenges of incorporating argumentation in SSI (Johnson et al., 2020), this study suggests that our teachers struggled to incorporate some components of SSI such as employing reflective skepticism and comparing multiple perspectives. It is important that these challenges be addressed in future PD workshops. Finally, participant teachers demonstrated development of their PCK of student understanding of assessment as a key component of SSI (Sadler et al., 2019) by asking their students to reflect and state their own position or solution at the end of the SSI debate. Through engaging in PD activities, experiencing SSI lessons as modeled by PD facilitators and guest speakers, and through guided lesson development, participant teachers expanded their PCK towards SSI.

While these findings are promising, reflecting the initial success of the USTRIVE project for developing teacher PCK towards SSI, additional research is needed. Recommendations for future research include: (a) the development and utilization of an SSI classroom observation protocol to observe and study teachers' PCK in action during instruction, (b) direct analysis of teacher PCK with regards to students' thinking of SSI, and (c) analysis of PD effectiveness through observation of students as they engage and solve SSIs in the classroom.

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Appendix A: Lesson Plan Rubric

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

<table>
<tr><td colspan="3">A) Identify the Issue: Identify the socioscientific issue by reviewing “newspapers, books, Internet sources, professional science education-related journals and television/movies for current issues related to your subject matter and course objectives. There are local and global controversies related to almost any science topic. As you explore topics, consider students’ interests and selected topics with relevance to their lives and the [school’s] curriculum” (Zeidler & Kahn, 2014, p. 31).</td></tr>
<tr><th>Level 3</th><th>Level 2</th><th>Level 1</th></tr>
<tr><td>Lesson plan contains:
a) Debatable SSI explicitly stated and translated in the lesson
AND
b) Students are engaged in SSI by reviewing primary sources and/or real-world examples
OR
c) Debatable SSI is connected to students' lives</td><td>Lesson plan contains:
a) Debatable SSI implicitly stated and translated in the lesson
AND
b) Students are engaged in SSI by reviewing primary sources and/or real-world examples
OR
c) Debatable SSI is connected to students' lives</td><td>Lesson plan contains:
a) Debatable SSI explicitly or implicitly stated and translated in the lesson</td></tr>
</table>

<table>
<tr><td colspan="3">B-1) Knowledge: Explore and explain the underlying scientific phenomena: Think of opportunities for students to explore and explain the scientific phenomenon associated with the focal issue. This anchor phenomenon must be relevant to students’ everyday experiences, observable, complex, have associated data, text and images, and part of the school’s curriculum (Sadler et al., 2019). If anchor phenomenon is not present or unclear, then this element is scored as a zero</td></tr>
<tr><th>Level 3</th><th>Level 2</th><th>Level 1</th></tr>
<tr><td>All <u>three</u> components:
a) Explicit naming of the anchor phenomenon
b) Mechanisms and systems/functions (in science or mathematics) described
c) Connections of science or mathematical topics to SSI</td><td>Only <u>two</u> components:
a) Explicit naming of the anchor phenomenon
b) Mechanisms and systems/functions (in science or mathematics) described
c) Connections of science or mathematical topics to SSI</td><td><u>One</u> component:
a) Explicit naming of the anchor phenomenon</td></tr>
</table>

B-2) PCK: Explore and explain the underlying scientific phenomena: Think of opportunities for students to explore and explain the scientific phenomenon associated with the focal issue. This anchor phenomenon must be relevant to students' everyday experiences, observable, complex, have associated data, text and images, and part of the school's curriculum (Sadler et al., 2019). If anchor phenomenon is not present or unclear, then this element is scored as a zero		
Level 3	**Level 2**	**Level 1**
All <u>three</u> components: a) teacher relates anchor scientific phenomenon or mathematical system to students' everyday experiences b) teacher provides opportunity for students to observe the anchor scientific phenomenon or mathematical system c) teacher provides opportunity for students to use data, text, and/or images to explore and explain the anchor scientific phenomenon or mathematical system	Only <u>two</u> components: a) teacher relates anchor scientific phenomenon or mathematical system to students' everyday experiences b) teacher provides opportunity for students to observe the anchor scientific phenomenon or mathematical system c) teacher provides opportunity for students to use data, text, and/or images to explore and explain the anchor scientific phenomenon or mathematical system	<u>One</u> component: a) teacher relates anchor scientific phenomenon or mathematical system to students' everyday experiences b) teacher provides opportunity for students to observe the anchor scientific phenomenon or mathematical system c) teacher provides opportunity for students to use data, text, and/or images to explore and explain the anchor scientific phenomenon or mathematical system

C) Engage in STEM modeling: Allow students to engage in scientific modeling and reasoning through development, use, evaluation, and revision of scientific models. Models are used to convey and explain information as well as to predict future events. 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)		
Level 3	**Level 2**	**Level 1**
<u>Three or four</u> components: a) **students** develop models b) **students** evaluate **and/or** revise models c) **students** use models to convey information d) **students** use models to make predictions	<u>Two</u> components: a) **students** develop models b) **students** evaluate **and/or** revise models c) **students** use models to convey information d) **students** use models to make predictions	<u>One</u> Component: a) **students** develop models b) **students** evaluate **and/or** revise models c) **students** use models to convey information d) **students** use models to make predictions

D) 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 elements such as political, economic, ethical, and religious considerations.		
Level 3	**Level 2**	**Level 1**
Four or more components: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity	Two or three components: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity	One component: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity

E) Employ reflective scientific skepticism: Teach students to consider the following questions while reviewing their data and sources of information (Sadler et al., 2019).		
Level 3	**Level 2**	**Level 1**
Asks students to question **THREE OR MORE**: a) Biases that could affect the presentation of the information **OR** b) The author or organization disseminating the information **OR** c) The purpose and/or methodology for obtaining information **OR** d) The expertise and/or relevant experiences the author has **OR** e) Those who are disadvantaged/advantaged with respect to the SSI	Asks students to question **TWO**: a) Biases that could affect the presentation of the information **OR** b) The author or organization disseminating the information **OR** c) The purpose and/or methodology for obtaining information **OR** d) The expertise and/or relevant experiences the author has **OR** e) Those who are disadvantaged/advantaged with respect to the SSI	Asks students to question **ONE**: a) Biases that could affect the presentation of the information **OR** b) The author or organization disseminating the information **OR** c) The purpose and/or methodology for obtaining information **OR** d) The expertise and/or relevant experiences the author has **OR** e) Those who are disadvantaged/advantaged with respect to the SSI

F) 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.		
Level 3	**Level 2**	**Level 1**
Four or more perspectives: a) media b) scientists c) businesses d) politicians e) researchers f) public opinion g) political groups h) religious organizations i) environmental activists	Two or three perspectives: a) media b) scientists c) businesses d) politicians e) researchers f) public opinion g) political groups h) religious organizations i) environmental activists	One perspective: a) media b) scientists c) businesses d) politicians e) researchers f) public opinion g) political groups h) religious organizations i) environmental activists

G) 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.		
Level 3	**Level 2**	**Level 1**
All three components: a) use **their** data to explain **their** position and/or solution, b) explain the strengths and weaknesses of **their** claims, c) identify **their** personal biases and possible limitations.	Two components: a) use **their** data to explain **their** position and/or solution, b) explain the strengths and weaknesses of **their** claims, c) identify **their** personal biases and possible limitations.	One component: a) use **their** data to explain **their** position and/or solution, b) explain the strengths and weaknesses of **their** claims, c) identify **their** personal biases and possible limitations.

Sociotransformative Constructivism (sTc)

H) 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 in Rodriguez, A.J., Morrison, D., 2019; Zeidler, 2014)		
Level 3	**Level 2**	**Level 1**
All three components: a) Students provided avenue to elicit and voice their perspective on the SSI b) Students reflect on how their opinions changed over time with the unit of study c) Students are able to discuss the SSI's value to them in terms of cultural significance, social importance, and level of interest	Two out of three components: a) Students provided avenue to elicit and voice their perspective on the SSI b) Students reflect on how their opinions changed over time with the unit of study c) Students are able to discuss the SSI's value to them in terms of cultural significance, social importance, and level of interest	One out of three components: a) Students provided avenue to elicit and voice their perspective on the SSI b) Students reflect on how their opinions changed over time with the unit of study c) Students are able to discuss the SSI's value to them in terms of cultural significance, social importance, and level of interest

I) 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.		
Level 3	**Level 2**	**Level 1**
Students are engaged in learning activities that meet all of the following criteria: a) Tied to the everyday life of the learner b) Inquiry-based, hands-on, minds-on c) Socioculturally relevant	Students are engaged in learning activities that meet 2 of the following criteria: a) Tied to the everyday life of the learner b) Inquiry-based, hands-on, minds-on c) Socioculturally relevant	Students are engaged in learning activities that meet 1 of the following criteria: a) Tied to the everyday life of the learner b) Inquiry-based, hands-on, minds-on c) Socioculturally relevant

J) Dialogic Conversation: Provides opportunities for students to voice their own reasons (emotional tone, ideological, and conceptual positions) the speaker chooses in a specific context		
Level 3	**Level 2**	**Level 1**
Three or more opportunities for students to co-construct knowledge through different forms of dialogue with classmates, teachers/other adults, experts, etc.	Two opportunities for some students to co-construct knowledge through different forms of dialogue with classmates, teachers/other adults, experts, etc.	One opportunity for some students to co-construct knowledge through different forms of dialogue with classmates, teachers/other adults, experts, etc.

K) Metacognition: Provides opportunities for students to use their learning experiences to transform (actions) themselves and others		
Level 3	**Level 2**	**Level 1**
a) Two or more opportunities for students to reflect on their learning experiences with regard to its impacts on themselves and others **AND** b) Reflects on what their role is in influencing this SSI (agency)	a) One opportunity for students to reflect on their learning experiences with regard to its impacts on themselves and others **AND** b) Reflects on what their role is in influencing this SSI (agency) **OR** c) Multiple opportunities for students to reflect on their learning experiences with regard to its impacts on themselves and others	a) One opportunity for students to reflect on their learning experiences with regard to its impacts on themselves and others **OR** b) Reflects on what their role is in influencing this SSI (agency)