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Abstract

This case study addresses the pedagogical challenges teachers face in incorporating elements of socioscientific issues (SSI) when planning science and mathematics lessons. In order to effectively plan and teach SSI lessons, teachers must develop pedagogical content knowledge (PCK) specific to unpacking elements of SSI such as identifying an issue that is debatable and relevant to students' lives, employing reflective scientific skepticism, and evaluating multiple perspectives. This study was guided by the following research questions: 1) In what ways, if any, did teachers' knowledge and instructional design of SSI change throughout the intensive series of workshops? 2) What areas of SSI required additional support? To answer our research questions, we analyzed changes in lesson plans from 29 teachers, mostly science and secondary, over the course of three intensive workshops as part of the Integrating STEM in Everyday Life Conference Series. Over the five month period, teachers worked in groups and with mentors to design and implement SSI lessons. Our findings show that teachers demonstrated positive changes in all SSI elements over the course of the workshops. However, deeper analysis reveals that teachers struggled to balance the social and scientific aspects of SSI. Moreover, our analysis suggests that teachers did not focus on the discursive nature of SSI in their lesson plans. Implications of our study include ways in which professional development programs can cultivate teachers' PCK of SSI in order to better support them in planning and implementing SSI lessons.

Introduction

Current education reform movements in science and mathematics advocate for teaching science, technology, engineering, and mathematics (STEM) disciplines through the development of knowledge, practices of science and engineering, and by solving real-world problems (National Research Council [NRC], 2007, 2013; Sadler et al., 2007). The socioscientific issues (SSI) framework provides authentic entry points into science curricula that allow for the development of functional scientific literacy skills and the ability to analyze multiple perspectives and varied sources of information on complex issues (Ziedler, 2014). While mathematics and computational thinking provide systems and tools for students to collect, analyze, and represent data, as well as study patterns and predict outcomes using mathematical and computer models (Kertil & Gurel, 2016), SSI facilitates student ability to apply the practices of mathematics and science to make logical predictions on contentious scientific issues while invoking emotions such as sympathy and empathy as they evaluate information (Powell, 2014). The practices of science and engineering focus on the systematic and iterative approach to study and understand the natural and designed world (NRC, 2012). In contrast, by engaging and studying STEM content through SSI, students are encouraged to reflect on their own personal experiences, prior knowledge, cultural background, and belief system as they inquire about and engage with ill-structured problems and controversial issues (Ziedler, 2014). Furthermore, SSI lessons extend beyond the study of nature and technology to areas such as citizenship education (Barrue & Albe, 2013), character and values (Lee et al., 2013), and the political, moral, cultural, and ethical aspects of the problem (Zeidler, 2016).

There are several benefits to supporting pre-service and in-service science and math teachers to incorporate SSI in their instruction. For instance, students who have engaged in learning through SSI have been found to exhibit the following benefits: improved critical thinking, evidence-based reasoning, ability to engage in scientific argumentation (Nuangchalerm, 2009), motivation to learn science topics, and to evaluate information and demonstrate sensitivity to multiple viewpoints (Saunders & Rennie, 2013). Research also indicates potential growth for teachers with respect to beliefs and instructional practice, including the development of cultural competence in evaluating human activities (Macalalag et al., 2019), and increased ability to engage teachers and their students in claims, evidence, and reasoning (Johnson et al., 2020).

Teachers face many challenges when attempting to incorporate SSI into their teaching. Learning to teach using SSI takes time and a personal professional investment by teachers to acquire the knowledge and skills necessary to support student learning (Hancock et al., 2019; Leden et al., 2007). Using SSI in classroom practice involves developing teachers' comfort and ability to help their students view scientific issues through a moral and ethical lens. This requires teachers to critically reflect upon their own beliefs and instructional practices in order to effectively engage students in SSI. Specifically, teachers must confront their own orientations toward science (e.g. Gray & Bryce, 2006) and acquire new instructional strategies to promote their students' ability to critically examine science issues. Science is more than the compilation of facts and skills to be mastered; the nature of science itself must be considered in order to shift instructional practice, including exploring "moral, social and ethical" issues in science (Gray & Bryce, 2006). However, research indicates teachers have difficulty moving their understanding of science education beyond teaching the facts (Ekborg et al. 2012).

Emerging research also indicates teachers encounter many challenges to effectively engaging students in two key scientific practices featured in the SSI framework: scientific argumentation and modeling (Johnson et al., 2020). For example, research has identified challenges including teacher knowledge of the key learning goals of scientific argumentation (McNeill et al., 2016), evaluating student arguments, and how to scaffold student engagement in argumentation, specifically supporting student reasoning and developing good argumentative prompts to guide instruction (McNeill & Knight, 2013). Scientific modeling can also pose a challenge for teachers (Stammen, et al. 2018). Modeling, which involves the representation of a physical or conceptual system and the impact of changes imposed on the system, is an important way for students to use scientific reason skills to develop conceptual understanding of scientific phenomena (Louca & Zacharia 2012). For example, Zhang et al. (2015) reported that many in-service teachers believed their scientific reasoning skills needed additional support through professional development. In most cases, teachers use models and modeling to explain a phenomenon or system, but do not use them for its analytic and predictive function (Windschitl & Thompson, 2006; Macalalag, 2012). Moreover, Windschitl and Thompson (2006) found that pre-service teachers typically considered modeling only as an extension of the scientific method. As a result, they had difficulty shifting their understanding of the nature and processes of science toward a modeling perspective.

The effective teaching of SSI requires the development of teachers' pedagogical content knowledge (PCK) in planning, teaching and reflecting on components of SSI instruction (Bayram-Jacobs et al. 2019). By studying teachers' PCK, we are able to develop professional development programs in order help teachers select SSI contexts that are personally relevant to students (Saunders & Rennie, 2013) and develop assessments based on how students are able to engage in argumentation that is anchored on their scientific knowledge and personal beliefs (Dolan, Nicholas, & Zeidler, 2009). Moreover, we will be able to understand their successes and challenges in designing and planning lessons that exhibit their PCK of instructional strategies, and this includes a teacher's ability to make appropriate choices about teaching and learning strategies in SSI (Magnusson et al., 1999). As a teacher of SSI, they must be able to incorporate several teaching strategies that 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, which are several essential components of SSI (Sadler et al., 2019). Although there is a body of literature on teachers' PCK in science education (Berry, Friedrichsen & Loughran, 2015; Gess-Newsome & Lederman, 1999), there is a need to study teachers' PCK while planning to incorporate SSI elements such as use of models and evaluating multiple perspectives in SSI lessons. Lesson planning has shown to be a useful tool for understanding and uncovering teachers' PCK of model-based scientific inquiry (Macalalag, 2012), student understanding and instructional strategies in SSI (Bayram-Jacobs et al. 2019), and critique and adaptation of SSI-oriented instructional materials (Forbes and Davis, 2008). In lesson planning, teachers consider students' background knowledge, skills and experiences, while they think about ways to effectively teach the big ideas of their lesson (Danielson, 1996).

We designed our current research project to address the pedagogical challenges teachers face in designing SSI science and math lessons through professional development. In particular, our study has been guided by the following research questions: 1) In what ways, if any, did teachers' knowledge and instructional design of SSI change throughout the intensive series of workshops based on their lesson plans? 2) What areas of SSI required additional support?

Literature Review

Defining SSI

There is a growing body of research that points to developing teachers' knowledge and implementation of SSI in their classrooms. Teachers who teach using SSI must learn how to include its key components (Table 1) in their instruction: (a) identify the issue, (b) explore and explain the underlying scientific phenomena, (c) engage in scientific modeling, (d) consider system dynamics, (e) employ reflective skepticism, (f) compare and contrast multiple perspectives, and (g) elucidate their own position or solution (Sadler et al., 2019). Thus, teaching using SSI requires teachers to integrate knowledge of science and social systems. However, balancing the social and scientific elements is challenging for teachers.

Table 1. Descriptions of SSI Elements with Categories

SSI Element	Category	Description
A. Identifying the issue	Social	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).
B. Scientific phenomenon	Scientific	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).
C. Engage in STEM modeling	Scientific	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)
D. Consider issue system dynamics	Social	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.Teach students to consider the following questions while reviewing their data and sources of information (Sadler et al., 2019).
E. Employ reflective scientific skepticism	Discursive	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.
F. Compare and contrast multiple perspectives	Social	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.
G. Elucidate own position/ solution	Discursive	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.

For example, in the process of preparing teachers to conceptualize lessons with SSI components, Forbes and Davis (2008) saw tensions on three interrelated goals for learning: "science concepts (ecosystem dynamics and trophic interactions), the impact of human activity on ecosystems and potential consequences, and decision-making about these issues" (p. 845). They found that teachers could interpret and emphasize different aspects of the same SSI element based upon their own comfort and instructional preference. Specifically, findings indicated that while one teacher focused on teaching the science content of SSI, another teacher prioritized helping her students connect the science content with their lives and engagement in reasoning and discourse. Similarly, Barrue and Albe (2013), investigated the instruction of middle school teachers implementing SSI and found variation in the interpretation of the goals and relative balance between the social and scientific components of the lessons. Their study suggested two competing views on the social elements of SSI, which they referred to as citizenship education: (a) encouraging social interaction with the goal of being able to live with others and (b) developing skills to evaluate multiple viewpoints, debate, and express one's position or solution. Based on this literature, SSI addresses two domains of knowledge and skill: science and social systems.

Research has found inherent tensions in the SSI framework for teachers to consider scientific habits of mind in their lessons, including scientific skepticism or questioning accepted claims, curiosity that leads to inquiry, and openness to new ideas. Scientific habits of mind directly relate to teachers' understandings of the nature of science (Ekborg et al., 2012). Specifically, teachers must see science as more than a collection of facts; teachers must be comfortable with ambiguity and multiple perspectives. Leden and colleagues (2017) highlighted a persistent instructional norm that science should focus on the "indisputable facts" rather than seeking to support the understanding of the processes of the natural world and the factors that affect them. These indisputable facts often become part of a standardized curriculum and, by extension, standardized assessment. Aydeniz et al. (2012) found that standardized testing "has a significant influence on science teachers' instructional and assessment practices in ways that are counter to the learning goals promoted by science education reformists" (p 247). Teachers reported the need to teach and assess "to the test" leaving little room for a reformed curriculum. Therefore, shifting teachers' beliefs about the nature of science, and how science should be taught, is a central challenge for effective implementation of SSI. Relatedly, Calik, Turan and Coll (2014) found pre-service teachers tend to trust arguments from authority figures rather than question and demand evidence, also leading to instruction that emphasizes scientific facts over scientific practices. Furthermore, in a study of secondary science teachers in Korea, Lee et al. (2006) found that while most participants believed that SSI should be incorporated into science classrooms, utilization of the SSI framework was superficial. They concluded that teachers needed to develop content understandings, pedagogical skills, and habits of mind, which they specified as "tolerance for ambiguity, critical thinking skills, skills in argument" (p. 113) in order to effectively teach science through the SSI framework. These research studies point to the importance of striking balance in instruction between the scientific, social, and discursive elements of the SSI framework (Sadler et al., 2019).

Implementation of SSI in the classroom also requires teachers to engage their learners in scientific skepticism; specifically questioning and critiquing scientific sources to identify biases. These elements of SSI are found to promote argumentation and discourse while learning scientific knowledge and eliciting personal beliefs (Dolan et al., 2009). According to Marco-Bujosa, McNeill, et al. (2017), "argumentation as a social process in which students construct arguments through interactions with their peers. The dialogic dimension of argumentation shifts the instructional goal to collaboratively making sense of phenomena and convincing others (Berland & Reiser, 2011), which differs greatly from the typical classroom discourse (Lemke, 1990), where students generally interact with the teacher rather than other students (Berland & Reiser, 2011)" (p. 142). Moreover, in the process of argumentation, students act like scientists and engineers as they make conclusions and solutions based on evidence, while evaluating competing ideas and methods (NRC, 2013). In addition to argumentation, teaching science through SSI has been found to support student learning of scientific concepts, engagement in scientific practices, and social citizenship. For example, teaching through SSI has been found to develop student critical thinking skills, ability to reason using evidence, and scientific argumentation skills for pre-service teachers in Thailand (Nuangchalerm, 2009). A study of in-service teachers in New Zealand found teaching science through SSI increased student engagement and motivation to engage in critique, justify their decisions, and demonstrate sensitivity and respect to a wide range of viewpoints (Saunders & Rennie, 2013).

Teacher Learning about SSI

SSI is a complex, interdisciplinary instructional model integrating content and social elements. SSI represents a significant instructional shift from traditional science and math instruction focused on content. As previously summarized, teachers must develop knowledge and practices with science content, science practice, integrate social systems into their instruction, and develop the ability to reflect upon their own scientific habits of mind. Research indicates teachers are more likely to change their practice if the professional learning experience includes several key principles, including: a distinct vision of effective practice, models of the desired instructional practice, a chance to apply what they learned in their classroom, and to reflect on the process and provide a learning community (Darling Hammond & McLaughlin, 1995; Louchs-Horsley, et al. 1998). Loucks-Horsley, Hewson, Love, and Stiles (1998) asserted ''[it is] difficult if not impossible to teach in ways in which one has not learned'' (p. 1). Assuming this to be true, professional development should be designed to engage teachers in learning through SSI activities from the perspective of students, which has been found effective for supporting teacher learning about and implementation of the science practices (e.g. Lowell & McNeill, 2020; Marco-Bujosa, Gonzalez-Howard et al., 2017). Thus learning for SSI should focus on "rich content" and include multiple iterative cycles of engagement with the content from different perspectives (Jeanpierre et al., 2005).

Challenges to shifting instruction to SSI that should be addressed and supported in professional development (PD) include teachers' abilities and willingness to critically evaluate their own instructional practice in order to question their assumptions about their discipline, instructional practice, and beliefs about students (Brookfield, 1987; Cochran-Smith & Lytle, 2011; Harland & Wondra, 2011, Slade, 2019). The ability to critically reflect is essential to transform their instruction to align with the goals and methods employed in SSI. Brookfield (1987) defined critical reflection as consisting of four processes: analyzing assumptions, being aware of assumptions, considering multiple perspectives related to the problem, issue, or phenomenon, and reflective skepticism. Critical reflection is central to teachers shifting their instructional practice to more effectively interrogate the habits of mind that influence teachers' proclivities for teaching math and science. As Brookfield (2017) stated, "Critical reflection is, quite simply, the sustained and intentional process of identifying and checking the accuracy and validity of our teaching assumptions" (p. 3, 2017).

Critical reflection is essential, yet challenging, particularly when the goals of the professional learning experience differ from the teachers' expectations (Richards et al. 2001). This is likely to occur with SSI, which involves such a significant instructional shift with respect to teachers' preferred practices and habits of mind. For example, Jeanpierre et al. (2005) uncovered a significant challenge presented when teachers' beliefs did not align with the intended outcome of the PD. Findings revealed a positive correlation between teachers' preliminary beliefs about the content of the PD and the ultimate change in teachers' practices. Schneider and Plasman (2011) reported that teachers' understanding of practice changes throughout their careers as a result of their learning and experiences. Over time, they develop a more complex and sophisticated vision of teaching and developing adaptive expertise in their instructional design. Teachers who are adaptive experts can think in flexible ways and are open to challenges (Bransford, 2004). Ball et al. (2008) assert that this flexible and connected knowledge of content and ways to make it accessible for student learning are critical to effective teaching.

Regardless, research has found that sustained, rich professional learning opportunities can promote teacher instruction with SSI. Leden et al. (2007), found that when engaging teachers in long term PD, teachers' knowledge of teaching about SSI can change and the nature of their reflections changed over time. Specifically, over the course of the three year extended PD, teachers were able to increase the number of SSI issues to discuss, were better able to connect SSI issues to scientific content with increasingly detailed ways and were increasingly able to identify the opportunities and challenges of incorporating a focus on Nature of Science (NOS) in their work. It should be noted that selection of SSI topics (Hancock et al., 2019) takes time. The authors reported that collaborative groups of teachers required time and space in order to grapple with the development of shared meaning and understandings about an issue. The outcome of this group work, being able to identify what a good issue may be, required each teacher to collaboratively agree to common understanding developed in the group and, at the same time, embrace their own context-based understanding.

Conceptual Framework: PCK and SSI

In order to conceptualize, plan, implement, and evaluate teaching of SSI, teachers must develop pedagogical content knowledge (PCK) specific to this domain separate from and in addition to their PCK for science teaching (Macalalag et al., 2019). According to Shulman (1986), PCK is a special amalgamation of subject matter knowledge and teaching practices that is essential to help learners of various backgrounds, prior knowledge, culture, and experiences learn concepts and skills during instruction. The teachers' PCK of teaching orientation and instructional strategies guide them as they conceptualize and operationalize teaching and learning 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). In particular, a teacher of SSI must consider not only the big ideas of the lesson, but also think about students' prior knowledge, interests, cultural backgrounds, and learning experiences as they utilize a context or an issue (Zeidler, 2014). Learning about students' backgrounds is especially important in regards to teachers' selection of SSI cases, so that teachers can align SSI cases to students' lives and make them personally relevant (Saunders & Rennie, 2013; Yerrick & Johnson, 2011). Moreover, a teacher of SSI must be able to create a classroom environment and select appropriate teaching methods in order 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). 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 their instructional practice (Cochran-Smith & Lytle, 1999). This involves teachers reflecting critically on their own instruction either individually or collaboratively (Cochran-Smith & Lytle, 1999) 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 inclusion of the discursive elements of SSI (e.g. questioning data from multiple sources) and teachers' ability to effectively implement lessons (Sadler et al., 2019) are central to teaching of SSI.

Lesson Planning as Evidence of SSI

Lesson planning is a ubiquitous practice for teachers and lesson plans are important artifacts of teaching. The processes of lesson design and the creation of lesson plans are windows into teachers' PCK of SSI as they utilize different instructional strategies to engage students in controversial topics (e.g. use of plastic bottles, sugar in drinks) by considering students' understanding of science and their difficulties. Analyzing lesson plans for evidence of PCK of SSI is appropriate, "because this knowledge is conceptualized as being constructed through the processes of planning, reflection, and teaching specific subject matter, it represents knowledge that is 'uniquely the province of teachers, their own special form of professional understanding' (Shulman, 1987, p. 8)" (Magnusson et al., 1999, p. 116). Moreover, because having well-developed PCK enhances teachers' abilities to facilitate student learning in their classrooms (Bayram-Jacobs et al., 2019), their instructional planning will reflect efforts to scaffold and support student conceptual understanding and development of skills. As teachers plan different components of their instruction, tensions and shifts in focus (e.g. content vs. practices, scientific vs. social aspects of the issue) arise (Forbes & Davis, 2008; Macalalag et al., 2019). For example, in a study of teacher instructional design for SSI, Forbes and Davis (2008) found, "teachers navigated multiple learning goals, as well as their own subject-matter knowledge, informal reasoning about SSI, and role identify, in their critique and adaptation of SSI-oriented science instructional materials" (p. 823). Thus, lesson plans may offer insight into teacher PCK as well as understanding of the key components of SSI.

In planning and preparation, interactions between teachers and curriculum materials come into play as: "(a) curriculum materials play an important role in affording and constraining teachers' actions; (b) teachers notice and use such artifacts differently given their experience, intentions, and abilities, and (c) 'teaching by design' is not so much a conscious choice as an inevitable reality" (Brown, 2009, p. 19). As teachers develop a more complex and sophisticated vision of teaching, this will be reflected in their instructional design efforts through adaptive expertise and flexible use of instructional strategies and activity structures (Bransford, 2004). Moreover, as teachers interact with curriculum and instructional materials, they analyze, critique, and modify them based on their own teaching orientations, which has been shown to change as a result of PD (Duncan et al., 2010). As a result, lesson planning has been shown to develop teachers' confidence of teaching case-based issues, environmental awareness, and social responsibility (Macalalag et al., 2019). Group lesson planning as part of PD has shown to positively impact teachers' thinking, intentions and actions around SSI teaching. In particular, most of the teachers included more than half of the SSI components such as scientific phenomena, system dynamics, social, political, and cultural aspects in a unit of study (Minken et al., 2020). In summary, these research studies pointed to the development of teachers' PCK in SSI through lesson planning and interaction with curriculum materials.

Methodology

This case study was guided by the following research questions: 1) In what ways, if any, did teachers' knowledge and instructional design of SSI change throughout the intensive series of workshops based on their lesson plans? 2) What areas of SSI required additional support? The case study design (Merriam & Tisdell, 2016) was selected to provide "an in-depth description and analysis of a bounded system" (p. 39): the Integrating STEM in Everyday Life sustained PD workshop series. This conference series took place over the course of five months (from November to March), and involved providing professional development workshops on the different components of SSI (Table 1) assisting teachers to develop and implement their own SSI lessons with the support of peer groups and mentors. To answer our research questions, we collected qualitative data in the form of lesson plans, which were collected in consecutive draft stages at each workshop, and analyzed using quantitative analysis of qualitative data (Chi, 1997).

Elements of SSI during the Kickoff Conference

The goal of the kickoff conference was to provide a full day of professional learning for teachers about SSI, Education for Sustainability, and ways to ground STEM teaching in real-world contexts. The conference began with a keynote speaker on environmental education and sustainability, followed by an introductory workshop on SSI in which teachers worked in groups to *A. Identify the issues* that fit the SSI framework (Table 1) to situate their lesson plans. After this introductory session, a variety of workshops centered on these themes were offered in breakout sessions; teachers had the opportunity to sign up for and attend three different workshops before coming back together as a large group for closing remarks. One of the workshops offered to teachers at our kickoff conference was *Waste Not, Want Not: Reducing Food Waste Through STEM and Civic Engagement*, in which teachers engaged in the SSI element of C. *STEM modeling*, particularly through the development and use of mathematical models, to *A. identify the issue* regarding financial impact of unnecessarily discarded uneaten school lunches on a school district (Minken et al., 2020). The teachers then worked collaboratively to *G. Elucidate their own position and solution*, another SSI element, with respect to what should be done about this food waste from the perspective of a student. In doing so, teachers considered a third SSI element, *D. Issue System Dynamics*, specifically of economics, sustainability, and health. Through this experiential learning activity, teachers were able to develop an understanding of how to incorporate SSIs in their own classroom lessons.

A second workshop, *Analysis of Effects on Life-Cycle Development using Traditional Herbal Remedies*. In this context, the SSI under consideration was the value of traditional and indigenous medicines as compared to their modern medicine counterparts. In exploring this SSI, the facilitators focused on how the *B. Scientific phenomenon* of how living organisms react to different foods, specifically in terms of both traditional/cultural natural remedies elucidated by participants (Minken et al., 2020). The facilitators then allowed the participants to explore this *B. scientific phenomenon* more deeply, in the context of the *Drosophila* species of fly, by showing how different traditional remedies affected various Drosophila specimens in vials, which participants were allowed to examine. Use of *B. Scientific phenomena* to engage students in an SSI is an important element of the SSI framework (Sadler et al., 2019). After the conclusion of the Integrating STEM in Everyday Life kickoff conference, participants were asked to fill out a program evaluation form, which was used to plan the subsequent intensive workshop series to help teachers design and implement SSI lessons with their students. Also, opportunities to participate in the intensive workshop series were announced.

Elements of SSI during the Intensive Workshops

The three workshop sessions were held over the course of five months from November 2019 to March 2020. Teachers worked with facilitators and mentors to develop and implement lessons in their content area that aligned to the SSI framework. The goals of this workshop series were to enhance the growth of STEM educators at all levels of their professional trajectory so as to (a) design, develop, and share place-based STEM learning experiences using the SSI framework in lesson planning and implementation, (b) positively impact students' STEM knowledge, skills and self-efficacy (c) provide opportunities for network development for professional collaboration across schools and districts between pre-and in-service teachers, and (d) encourage and develop teacher leadership. Teachers were expected to develop, teach, and revise SSI lesson plans using a provided template (Appendix A).

These workshops were intentionally planned to facilitate teachers' development and implementation of SSI lessons by providing teachers with peer groups and mentors to work with, and also by demonstrating the different elements of an SSI lesson through sample lessons and resources (Appendix B). To do this effectively, teachers participated in two sample lessons modeled by different workshop facilitators, one at each of the first two intensive workshops. While each sample lesson was meant to demonstrate all elements of SSI, different elements were highlighted in each lesson, as shown in Table 2. For instance, in the first sample lesson, the SSI elements *A. The Identifying the issue*, *C. Engage in STEM modeling*, *D. Consider issue system dynamics*, and *E.*

Employ reflective scientific skepticism were highlighted, the second sample lesson modeled emphasized the SSI elements *B. Scientific phenomenon*, *F. Compare and contrast multiple perspectives*, and *G. Elucidate own position/solution*.

Table 2. Examples of SSI Elements Modeled through Intensive Workshop Series

SSI Element	Category	Examples in the Workshops and Lesson Planning
A. Identifying the issue	Social	"How do our choices of cars impact our world? Should government have a say in which choices we are able to make or should we have free choice in making our decisions?" -- Intensive workshop 1
B. Scientific phenomenon	Scientific	Teachers were shown a video about CRISPR and gene editing technology, and guided to explore the phenomenon further in groups by looking up primary sources and news articles. -- Intensive workshop 2
C. Engage in STEM modeling	Scientific	Teachers used and analyzed mathematical models to determine the relative fuel efficiencies of top selling vehicles in the U.S. They also used their models to compare and predict the carbon dioxide emissions from the U.S. Clean Care Act -- Intensive workshop 1
D. Consider issue system dynamics	Social	Teachers considered the impacts of car buying in terms of various issue system dynamics, including health, nature, economics, and politics. -- Intensive workshop 1
E. Employ reflective scientific skepticism	Discursive	Teachers researched the impacts of government regulation and argued based on this evidence whether the government should impose these restrictions and why. In doing so, they considered potential impacts of various regulations and the implications of "business as usual." -- Intensive workshop 1
F. Compare and contrast multiple perspectives	Social	Teachers worked in small groups at their tables, and picked the role of a stakeholder from an envelope that they used to navigate this activity. Teachers then joined their affinity group (others who also had the same stakeholder perspective). Teachers were asked to determine their group's values, and which of these they would use to gather data on the issue of gene editing? Based on their assigned perspective, teachers found pros and cons of gene editing individually using the Socioscientific Argument Outline (Appendix C) before discussing their individual findings with their affinity group, and then finally with their original group (with members of different stakeholder perspectives). -- Intensive workshop 2
G. Elucidate own position/solution	Discursive	Teachers were asked to consider their own perspective on the issue of gene editing after reflecting on their research and group discussions involving multiple perspectives. In this way, teachers elucidated their own position with respect to the use of gene editing in humans as well as reflecting on their reasoning with regard to why they felt that way. -- Intensive workshop 2

In the first workshop, teachers were introduced to Sadler et al.'s (2019) SSI Framework through engagement in a sample SSI lesson, after which participants were divided into groups and assigned a mentor to help them begin to develop their own SSI lesson. The second workshop exposed teachers to strategies they could use to incorporate the SSI element of comparing and contrasting multiple perspectives. At the third workshop, which was adjusted due to COVID-19 to be virtual, teachers presented and discussed their developed SSI lessons.

At the first intensive workshop session, teachers were presented with an overview of the SSI framework, and participated in a sample SSI lesson in mathematics. This lesson challenged the teachers to grapple with the SSI dilemma of whether or not people should have free choice, or be subject to government regulation in the interest of fuel efficiency and the impact of car exhaust on climate change, when shopping for a new car. In completing this lesson, teachers were tasked with looking up information about car specifications and climate change from a variety of sources to consider various *D. Issue system dynamics*, and. *C. Engaging in STEM modeling* by using mathematical models to analyze the relationships between these *D. Issue system dynamics* in order to *G. Elucidate their own position/solution* with respect to this SSI. At the conclusion of the sample lesson, teachers were asked to come up with a variety of ways that they could assess student learning at the conclusion of such a lesson.

Following this sample lesson, teachers broke out into groups that were heterogeneous with respect to teachers' content areas and teaching status: each teacher wore a nametag that had two different colored dots, one represented pre-service/in-service teaching status, and the other represented teachers' content areas. Teachers were directed to break out into groups of four or five, and to try to have members with all the different colored dots in their group. The purpose of using heterogeneous grouping was to provide teachers with opportunities to work together with others who might have different perspectives on developing an SSI lesson, thereby addressing *G. Comparing and contrasting multiple perspectives*, a foundational element of SSI (Sadler et al., 2019), and to help teachers adopt an inquiry stance with regard to their PCK as described by (Cochran-Smith & and Lytle, (1999). Each group was then assigned a mentor from one of the partner universities, and moved with their mentor to a separate area to begin working on developing an SSI lesson plan using the provided lesson plan template (Appendix A). These lesson plans were not limited to a single class period, and were designed to facilitate a longer lesson cycle that aligned with the 5E and SSI frameworks. At the conclusion of the first session, teachers were asked to continue working on their lesson plans on their own, and were told that their mentors would check in with their group prior to the following intensive session. The lesson plan template, mentor, and fellow group members were meant to help provide support to teachers as they developed their lessons: all members of a group, including the mentor, were encouraged to share contact information with each other so that teachers could reach out for support when needed.

At the second intensive workshop session, teachers shared progress on their lesson plans, participated in a PD session on incorporating *G. Comparing and contrasting multiple perspectives* into their lessons, and spent time working with their mentor groups refining their lesson plans. In the PD session, teachers, seated in groups at tables, were assigned different stakeholder perspectives on the SSI of gene editing and designer babies: Should parents be allowed to use gene editing technology to customize their children's physical features (e.g., eye color, height, skin color, etc.). Such stakeholder perspectives included a parent, business person, medical researcher, student and politician. For instance, a business person might argue that the use of this technology could enable people to be more productive without sacrificing their health, or that much money could be made by marketing this technology to particular demographics, while a politician might argue that allowing such technology for these purposes would lead to creation of a new industry and, by extension, countless new jobs, or that this technology might be viewed as "playing God" by their constituents and would not be supported or accepted. Teachers then broke out into homogenous groups to research the SSI and discuss what their stakeholder's perspective might be regarding the SSI, using a graphic organizer (Appendix C) to guide their thinking. After discussing the SSI in homogenous groups, teachers returned to their original (heterogenous) group to discuss their opinions on the issue with respect to their assigned stakeholder. Teachers were then directed to break character and discuss the SSI in terms of their own personal perspective rather than the assigned stakeholder perspective, which added a layer to the discussion by encouraging teachers to compare and contrast their own perspectives with that of the perspectives represented in the activity, and in doing so *G. Elucidate their own position/solution*. Further, teachers were prompted to consider the ways in which these perspectives might intersect within various individuals. For example, a given stakeholder might be a business person and a parent, while also going back to school as a student in higher education, simultaneously inhabiting three of the perspectives isolated in our activity. Following this, teachers reflected on the experience in terms of what this activity does for students and how they might implement it, or some variation, as a teacher. This developed into a whole group discussion on the benefits of incorporating multiple perspectives this way, as well as some adjustments the teachers might make if they were to implement this lesson with their own students. These instances of experiential learning were important for teachers PCK development, as Schneider and Plasman (2011) showed how teachers' understandings change and evolve through their experiences, which can help them to develop more robust instructional practices.

Due to school shutdown measures resulting from the COVID-19 pandemic, only five teachers reported being able to fully implement and teach their lessons. To better support our teachers, and to account for these unforeseen changes, we moved our final intensive workshop to an online format. In this third workshop, one of the teachers who had successfully taught his lesson presented to the rest of the teachers an account of the process and lessons learned. Following the presentation, teachers engaged in a discussion regarding the SSI framework as it relates to education, the process of instructional design and classroom enactment, and how future instruction of SSI could be affected by the school closures and online learning. This discussion allowed teachers to engage in critical reflection of their knowledge and implementation of SSI, which is important for essential elements of effective SSI instruction (Harland & Wondra, 2011; Forbes & Davis, 2008).

Research Context and Participants

This study was conducted over the course of a sustained professional development (PD) workshop called Integrating STEM in Everyday Life. The PD consisted of an initial kickoff conference followed by a series of three workshops (Minken et al., 2020). This PD was the result of partnerships between multiple universities and a large urban school district in the northeastern United States. Facilitators provided PD sessions on the Socioscientific Issues (SSI) framework described by Zeidler and Kahn (2014) and Sadler et al., (2019). The kickoff conference was held at a large public university in an urban area in the northeastern United States and was attended by over 80 educators. Table 3 and Table 4, below, show the participant demographics for teachers who submitted Lesson Plan Iteration 3 only, or all Lesson Plan Iterations 1-3, respectively.

Table 3. Participant Demographics with Lesson Plan Iteration 3

Subject Area (n=27)			Grade Level (n=27)			Teaching Status (n=29)		
Subject Area	n	%	Grade Level	n	%	Teaching Status	n	%
Science	12	44%	Elementary (K-5)	5	19%	Pre-service	11	38%
Mathematics	8	30%	Secondary (6-12)	21	78%	In-service	18	62%
Science & Mathematics	3	11%						
Technology	1	4%						
Other	3	11%						

Note. One participant indicated the subject area but not grade level.

Participants were recruited through newsletters, website postings, a district teacher information board, and in person announcements at the Integrating STEM in Everyday Life kickoff conference described in Minken et al. (2020). Teachers received a stipend for participating in the intensive workshop series. Participation in the research study was optional; teachers could still attend the workshops and receive the stipend regardless of whether or not they opted into this study. The research went through an ethical review process, and a consent form was provided to all participants that included descriptions of the scope of participation, confidentiality protocols, and the risks and benefits of participation. All 29 participants consented to participate in this research.

Table 4. Participant Demographics with All Lesson Plan Iterations (1-3)

Subject Area (n=17)			Grade Level (n=17)		
Subject Area	n	%	Grade Level	n	%
Science	8	47%	Elementary (K-5)	3	18%
Mathematics	5	29%	Secondary (6-12)	13	76%
Science & Mathematics	1	6%			
Technology	1	6%			
Other	2	12%			

Data Sources

The purpose of this case study was to explore how in-service teachers' knowledge and implementation of SSI changed over a sequential three-stage intensive workshop series. The data sources were lesson plans created by the teachers. Teachers provided access to their plans through online folders in a shared Google Drive. These folders allowed for the groups to collaborate with each other and their mentors on thinking and writing their lesson plans. The original lessons for each were copied and all identifiable personal and school information were removed. Each participant was assigned a unique identifier that indicated both the individual teacher, their group, and which iteration their lesson came from. This allowed the authors to keep track of who submitted, and the Lesson Plan Iterations. The authors referenced and used these labels while coding.

All participants completed at least one draft of their lesson plan, with most utilizing the lesson plan template provided (Appendix A). While all teachers worked to create SSI lesson plans, some lesson plans were inaccessible at the time each Lesson Plan Iteration was downloaded due to permissions errors associated with Google Docs. We were unable to follow up with participants to request access, and so these lesson plans were not included in our data sources. When comparing the scientific, social, discursive aspects of SSI (Table 4), we analyzed data from Lesson Plan Iteration 3, which we were able to collect from 27 participants. In analyzing our data, we analyzed both overall success and growth over time. To analyze overall success, we coded Lesson Plan Iteration 3 from our 27 teachers to investigate their sophistication of knowledge and implementation of SSI at the conclusion of our workshop series. On the other hand, to analyze the growth of our 17 teachers over time, we looked at changes in teachers' lesson plans from Lesson Plan Iterations 1, 2, and 3. Out of the 29 participants, we received Lesson Plan 3 from 27 participants and all Lesson Plan Iterations (1 - 3) from 17 teachers. Some participants did not submit one or more Lesson Plan Iterations over the course of the workshop and others did not upload their documents to the shared Google Drive Folder (see Table 5).

Table 5. Number of Participants from Each Data Source

Number of participants	Number of unique lesson plans	Data Sources
17	14	Iterations of Lesson Plans 1, 2 and 3
27	21	Lesson Plan 3

Additionally, some teachers chose to work more collaboratively with their group members than others, as evidenced by the fact that five of the lesson plans submitted were group lesson plans or lesson plans that teachers developed with a partner. Table 5 shows how the unique lesson plans we analyzed are attributed to multiple teachers (e.g., 17 teachers created a total of 14 unique lesson plans). Because 14 teachers each provided us with three iterations of lesson plans (42 total), and an additional seven teachers provided us with a lesson plan for iteration three, we coded a total of 49 lesson plan iterations in this study. When analyzing these lesson plans, each teacher was assigned a score that represented their contribution if it was specifically identified in the lesson plan, otherwise, each teacher received the same score as that of the group lesson plan. This was done so that lesson plans would be effectively weighted by the number of teachers who worked to develop them.

Data Analysis of Lesson Plans

The authors conducted a quantitative analysis of qualitative data (Chi, 1997) through which each lesson plan at each stage was coded using the coding guide (Appendix B), which was adapted from the SSI components described by Sadler et al., (2019). Because the original *Elements of an SSI Lesson's* descriptors were in paragraph form and binary, the authors took the verbiage of each element and deconstructed it into its component parts in order to make a rubric-like coding guide in an attempt to quantify sophistication with respect to teachers' ability to implement SSI. For instance, the following element, *A. Identify the Issue*, expressed as "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) became, "[the] lesson plan contains: (a) Debatable SSI explicitly stated and translated in the lesson, (b) students are engaged in SSI by reviewing primary sources and/or real-world examples, (c) debatable SSI is connected to students' lives," in the coding guide (Appendix D). The component parts of the descriptors were then analyzed for their import to the SSI code element and where appropriate, descriptors that were essential to the application of the element were listed first as (a). For instance, having a debatable SSI explicitly stated and translated is more fundamental to that code element than students engaging in SSI by reviewing primary sources, or having a debatable SSI connected to students' lives, which is why it is listed first and assigned an (a).

Organization of these component parts allowed for the coding guide's elements to be divided into three levels and assigned point values of one (lowest) to three (highest). In rating the lesson plans, a rating of one was assigned if there was minimal evidence for the element's component parts (descriptors), up to a three which indicated either the lesson covered each component part, or reached the minimum complement required for that level, as defined in the coding guide (Appendix D). For instance, using the aforementioned element, a Level 3 rating includes (a) a debatable SSI explicitly stated and translated in the lesson, and (b) students engaged in SSI by reviewing primary sources and/or real-world examples, or (c) a debatable SSI connected to students' lives. While in level 2 rating includes (a) 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) a debatable SSI is connected to students' lives. A Level 1 rating only includes (a) a debatable SSI explicitly or implicitly stated and translated in the lesson. We provided examples for each SSI element in our findings and Appendix D.

Similar to *A. Identify the Issue*, that we described above, Table 6 contains categories and element components that we developed for each of the SSI elements, including B-1. Knowledge of Scientific Phenomenon, B-2. PCK of Scientific Phenomenon, C. Engage in STEM Modeling, D. Consider Issue System Dynamics, E. Employ Reflective Scientific Skepticism, F. Compare and contrast multiple perspectives, and G. Elucidate own position/solution.

Table 6. Components of SSI Elements

SSI Element	Category	Element Components		
A. Identifying the issue	Social	(a) a debatable SSI explicitly stated and translated in the lesson (b) students engaged in SSI by reviewing primary sources and/or real-world examples (c) a debatable SSI connected to students' lives		
B-1. Knowledge of scientific phenomenon	Scientific	(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		
B-2. PCK of scientific phenomenon	Scientific	(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	Scientific	(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	Social	(a) political (b) cultural (c) economic	(d) ethical (e) religious (h) health	(g) nature (h) equity
E. Employ reflective scientific skepticism	Discursive	(a) biases that could affect the presentation of the information (b) the author or organization disseminating the information (c) the purpose and/or methodology for obtaining information (d) the expertise and/or relevant experiences the author has (e) those who are dis/advantaged with respect to the SSI		
F. Compare and contrast multiple perspectives	Social	(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	Discursive	(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		

Note: Components should be observable within a lesson plan.

The codes were grouped into three categories: social, scientific, and discursive codes for the purpose of analysis. The social codes consisted of *A. Identify the issue, D. Consider issue system dynamics,* and *F. Compare and contrast multiple perspectives*. These were considered social codes because they revealed the degree to which the lessons considered political, moral, cultural, and ethical aspects of the problem (Zeidler, 2016), citizenship education (Barrue & Albe, 2013) and values (Lee et al., 2013) class. The science codes, *B-1. Knowledge of scientific phenomenon, B-2. PCK of scientific phenomenon,* and *C. Engage in STEM modeling*, were designated as such due to their straightforward scientific nature. Finally, the discursive codes *E. employ reflective scientific skepticism* and *G. Elucidate own position/solution* contribute to the discursive nature of SSI. These groupings allowed us to add a level of nuance in our analysis of teachers' knowledge and instructional design of SSI and the areas in which they might need more support.

All lesson plans were double coded by the first and third authors with the resulting interrater agreement (Marshall & Rossman, 2011) being 89%. The first and third authors trained themselves on the use of the coding guide independently, coding one to two lesson plans (< 10% of 49 lesson plan iterations) at a time before comparing codes and noting disagreements. The coders then used those to clarify, adjust, and refine the coding guide. These revisions and refinements were presented to the remaining authors for comment before repeating this reflective cycle again. This cycle continued until the coders were able to reach agreement on four lesson plans in a row (< 10% of 49 lesson plan iterations) without requiring further refinement of the coding guide to resolve disagreements. At that point, the coders used the final version of the refined coding guide to independently evaluate all of the lesson plans from each iteration. The number of individual codes that the coders agreed upon were tracked in a spreadsheet, as well as the number of codes disagreed upon. The coders then discussed all disagreements, after which the coders were able to agree upon 99% of all codes. Interrater reliability was calculated by dividing the number of agreed upon codes by the total number of codes, and then multiplying by 100 to produce a percentage representing the overall agreement.

We used data from these 27 teachers' lesson plans (Table 3 and Table 5) to describe teachers' knowledge and implementation of SSI at the conclusion of our intensive workshop series. When calculating growth scores for each SSI element, we used data from the 17 participants who made all three Lesson Plan Iterations accessible (Table 4 and Table 5) to calculate average scores for each element in each Lesson Plan Iteration, and then subtracted the Lesson Plan Iteration 1 average score from the Lesson Plan Iteration 3 average score for each element. To further describe teachers' lesson plans in terms of how they addressed the scientific, social, and discursive components of the SSI, we created composite scores to represent these scientific and social aspects by adding the average scores for the three science codes to the average of the three social codes. To best illustrate this comparison, we used data from the third and final Lesson Plan Iteration for our social and scientific composite scores.

Finally, these growth score changes were calculated on a scale of zero to three (levels 0 to 3), although the observed average changes ranged from 0.18 to 1.76. In order to capture the nuances of these changes, we described the group the relative magnitudes of changes into small, medium, and large changes as follows: average changes between 0 and 0.75 were considered to be small changes, average changes between 0.76 and

1.25 were considered to be medium changes, and average changes above 1.26 were considered to be large.

Findings: Teachers' Knowledge and Implementation of SSI

Overall, there was growth in teacher PCK of SSI evidenced in lesson plans. However, there was variation across the scientific, social, and discursive elements and the balance between these elements in instructional design. We present these findings as three themes. The first addresses teachers' PCK, while the second and third themes describe elements requiring additional support.

Finding 1: Positive Changes in Teachers' Knowledge of SSI

Our first finding is supported by the positive changes and growth from Lesson Plan Iteration 1 to 3 in several elements of SSI (see Figure 1). We found that teachers demonstrated large (growth score greater than 1.25) positive changes in the following elements of SSI: *B-2. PCK of scientific phenomenon*, *C. Engage in STEM modeling*, *D. Consider issue system dynamics*, and *F. Compare and contrast multiple perspectives*. This is particularly surprising in that, during Lesson Plan 1, only 18% (n=4) of teachers (all of whom were part of the same group) had lesson plans that were coded as Level 1 in *B-2. PCK of scientific phenomenon*, while all other teachers received Level 0 on this code. More teachers were able to incorporate the SSI element of *D. Consider issue system dynamics* into the Lesson Plan 1, with 50% of teachers (n=11) receiving a Level 1 and 23% of teachers (n=6) scoring a Level 2. All 22 teachers who submitted Lesson Plan Iteration 1 scored Level 0 in *C. Engage in STEM modeling* and *F. Compare and contrast multiple perspectives*. By Lesson Plan 3, however, 65% of teachers (n=11) had grown 2 or 3 levels in three or more of these areas, and 68% of teachers (n=19) were scoring Level 3 in at least one of these four areas.

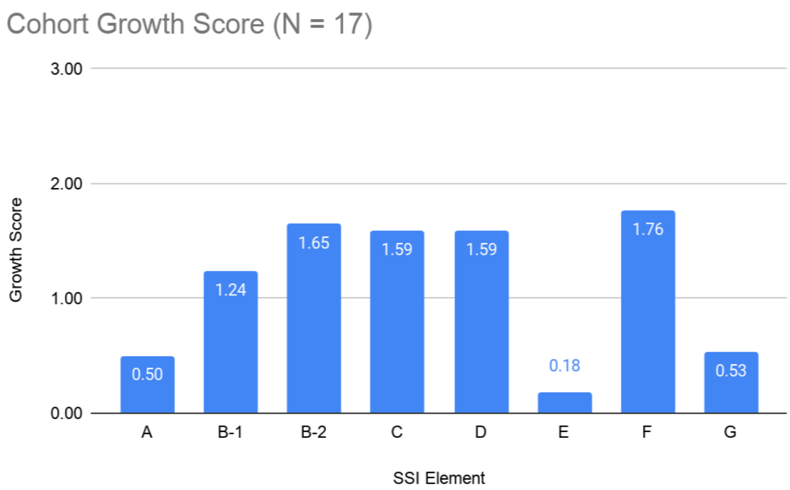

Figure 1. Growth Scores of SSI Elements

For instance, in his Lesson Plan Iteration 3, Mr. Claitt (pseudonyms used throughout) described an activity that showed *B-2. PCK of scientific phenomenon* that represents a Level 3. In Mr. Claitt's own words:

> *Show the Classical vs. Transgenic Breeding video [component b]. Then discuss examples of plants that have been traditionally bred for certain characteristics (e.g., firmer or sweeter tomatoes, wilt-resistant cucumbers, etc.). If time allows, have teams look at seed catalogs [component a] to identify two food plants and the specific different characteristics for which they have been bred. Then show the Bt Corn video so students can compare how plants are being genetically modified by new technologies. In pairs, have students discuss whether or not they think corn should be genetically modified and why.*
>
> *[Then,] have students do the Engineer a Crop: Transgenic Manipulation Web activities [component c], including both 'Selective Breeding' and 'Transgenic Manipulation.' Then, as a class, discuss the similarities and differences between selective breeding and transgenic manipulation.* (Mr. Claitt, Lesson Plan Iteration 3, Engage)

Through these learning activities, Mr. Claitt is making the phenomenon of GMOs relevant to students' everyday experiences by discussing GMOs that students have experience with and showing them examples using a seed catalog. In this lesson, the teacher allows students to observe the scientific phenomenon through the videos on GMOs, and provides opportunities for students to use data, text, and images to explore the scientific phenomenon in greater depth using the Engineer a Crop web activity. These particular lesson components demonstrate a Level 3 sophistication in terms of *B-2. PCK of scientific phenomenon*.

While we did see large growth in teachers' sophistication of *C. STEM modeling* as shown in their lesson plans, there were only 21% of teachers (n=6) who scored a Level 3 in this area of SSI. One of these teachers, Ms. Washington did so by looking at the intersection of forces, space travel, and GMOs. In her lesson plan, she described an activity in which:

> *Students are [given 10] plants (actual, literal moringa seed plants, in little cups) per group of 2-4, and a budget. The goal will be to get most of their plants (>5 plants) to the moon, where a hungry vegan astronaut is waiting. The 'journey' will include launch, travel, and landing, and the plants will go through trials at each stage. During the launch stage, plants will have to make it up through the 'atmosphere' without being broken (which will be simulated by someone dumping 'space debris,' which is really just potting soil and rocks, on a plant as it's lifted up from below), travel through space without falling out of their containers (having the plants chucked across a field and caught), and landing safely on the moon (being dropped from about 10 meters up onto a tile floor).* (Ms. Washington, Lesson Plan Iteration 3, Alternative idea for activity)

In this activity, Ms. Washington has set up a scenario in which students must design a physical model to successfully complete a challenge. By engaging in this challenge, students are making predictions regarding how best to minimize impact to passengers and plants during a space flight, with specific consideration to impacts and changes in motion that a spacecraft might experience. Students are also forced to consider budgetary constraints in developing a successful physical model. Once students create their models, they must test out the predictions and assumptions inherent in their model design choices, and evaluate the effectiveness of their model:

> *Students may choose all GMO plants, all non-GMO plants, or a mix. The 'GMO' plants are more 'expensive' (you can have fewer of them), but include 'modifications' like being glued into their cups, containers for their cups, little cages so the leaves don't break off, different colored cups, etc. These modifications may or may not actually help the plant survive—that's for the students to think about, using what they know about physics in space at every stage of launch, travel, and landing. Students also can use their resources to build protective cases for the plants on their own, but these protective cases may not be as good as the GMO plants. Students will have to do cost-benefit analyses and justify it in their budget and explanation.* (Ms. Washington, Lesson Plan Iteration 3, Alternative idea for activity)

In this activity, Ms. Washington's students are developing physical models of GMOs that they are using to make predictions about how well they will hold up to the forces associated with rocket launch and landing during space travel. Students are also encouraged to evaluate the effectiveness of their model based on the results of their investigation, in which they test their predictions. Although she did not have students revise their models based on this data, nor did she use their model to explain related phenomena, we still considered this a Level 3 in terms of *C. STEM modeling* based on our coding guide due to the presence of the aforementioned components.

Another teacher, Ms. Rodriguez, in her lesson plan demonstrates a Level 3 of *D. Consider issue system dynamics*. As was common in lesson plans incorporating this SSI element, in Ms. Rodriguez's lesson plan, students make use of online media such as articles and videos to see and hear about the issue system dynamics at work with respect to the established SSI. Specifically, Ms. Rodriguez articulates this in her lesson plan as follows:

> *Show the CNN video and provide the students with the articles. They will work in groups to read the articles and report out to everyone. The students will explore the [State] policy about lead in schools and discuss ways to find out what our school's policy is.* (Ms. Rodriguez, Lesson Plan Iteration 3, Engage and Explore)

Ms. Rodriguez provides links to a variety of videos and news articles that explore the various *D. issue system dynamics* associated with their SSI, including health, government regulation and politics, economics, and equity. The articles and videos referenced in Ms. Rodriguez's lesson plan include the Lamotte's (2018) news article and video reporting on the health issues of lead in drinking water and at home, the BBC News (2016) video describes how government regulations, driven by economic concerns, lead to the health crisis caused by lead in drinking water in Flint, Michigan. The BBC News video goes even further to describe the problem through the lens of race and equity by illustrating public sentiment that this crisis, which unfolded "in a largely black city...would not have happened anywhere else," and that this "is not just a water crisis, it's a racial crisis." Finally, Ms. Rodriguez includes a video from CBS News (2019), which describes how government regulations, or more accurately a lack thereof, contribute to lead in the drinking water of many schools throughout the U.S., as well as an article from the Pennsylvania Department of Education (2020) describing Pennsylvania's policies on testing for lead in school drinking water for students to explore. Because Ms. Rodriguez was able to incorporate four examples, the lesson plan was scored as a three for *D. Issue system dynamics,* In Mr. Claitt's Lesson Plan Iteration 3, he described an activity that allows students to *F. Compare and contrast multiple perspectives* by engaging in an online activity featuring statements and viewpoints from scientists, political groups, politicians, environmental activists who are studying if GMO produced foods healthy or unhealthy for humans: *"Ask students to examine the Should We Grow GM Crops? Web activity. Discuss how they voted and which arguments most influenced their decision."* This web-based/Internet activity (Tyson, 2001) involved students reading a passage and voting "Yes" or "No" as to whether they think we should grow GM foods. Then, no matter what students chose, they are presented with an alternate view and asked to vote again.

Mr. Claitt then provided websites (PBS Online, 2001) with statements/viewpoints from scientists, political groups, politicians, environmental activists for students to consider. Afterwards, the lesson plan directed students to watch a video on salmon that were being genetically modified and the following questions were asked:

> *What allows transgenic salmon to grow in winter? What are some possible consequences if transgenic salmon escape from their pens into the ocean population? How might transgenic salmon affect the evolution of other salmon populations? Do you think the FDA should give Aquabounty permission to grow and sell transgenic salmon? Why or why not?* (Mr. Claitt, Lesson Plan Iteration 3, Explore and Explain).

After showing students a video on transgenic salmon, Mr. Claitt asks students to consider the perspectives of government agencies tasked with keeping people safe alongside the perspective of the company used as an example in the video that has a competing interest. In this way, Mr. Claitt prompts students to *F. compare and contrast multiple perspectives* in his analysis of the ethics of cultivating genetically modified organisms.

In summary, our analysis of lesson plans suggests that teachers showed positive changes in all components of SSI, particularly with respect to *B-2. PCK of scientific phenomenon*, *C. Engaging in STEM modeling*, *D. Considering issue system dynamics*, and *F. comparing and contrasting multiple perspectives* (see Figure 1). However, when we analyzed our lesson plan data in terms of scientific, social, and discursive codes, we found differences in the ways that teachers applied the SSI framework to their lesson plans. These differences are detailed in the following subsections.

Finding 2: Balance Between Social and Scientific Aspects of SSI

Findings also pointed to successes and challenges teachers face in striking an instructional balance between the social and scientific components of SSI. As shown in Figure 2, teachers struggled to provide equal attention to the social and scientific aspects of the SSI. The social aspects of SSI were represented by the following codes from our coding guide: *A. Identify the issue*, *D. Consider issue system dynamics*, and *F. Compare and contrast multiple perspectives*, while the scientific aspects of SSI were represented by the codes: *B-1. Knowledge of scientific phenomenon*, *B-2. PCK of scientific phenomenon*, and *C. STEM modeling*. Our analysis of teachers' lesson plans indicated that teachers placed larger emphasis on the social aspects of the SSI than on the scientific aspects of the SSI.

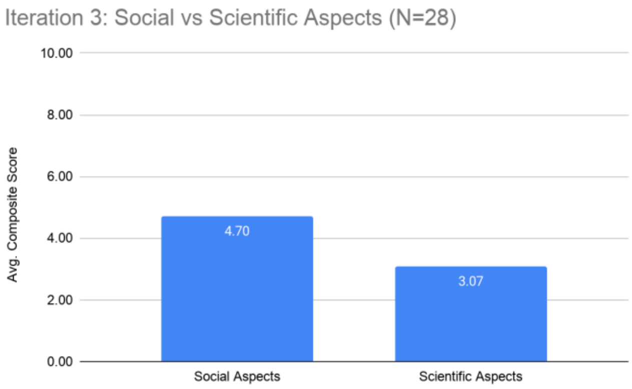

Figure 2. Average Composite Scores for Social and Scientific Elements of SSI

For example, Ms. Lee was one of the 65% of teachers (n=19) who showed a higher level of sophistication with respect to the social aspects as compared with the scientific aspects of SSI in their lesson plan. She describes her SSI as "Small level changes, like urban planting, can uplift marginalized communities and create lasting environmental impacts." Despite a connection between social and scientific topics, this does not meet our criteria of an explicitly stated SSI because there is not a clearly debatable issue under examination in Ms. Lee's lesson plan. Instead, however, we considered this to be an implicit SSI related to gardening, which was translated into the lesson by engaging students in primary sources and real-world examples. In the following excerpts, the teacher asked students to review articles from the primary sources in order for them to *A. Identify the issue* of SSI in urban gardening:

> *[Discussion 1] Individual reading: 6 students will share out to create a 3x3 of class notice and wonders Students will read Hard-working beauty and note 3 notices and 3 wonderings. Students will be selected from the random cup to share out one notice or wonder.*
>
> *[Discussion 2] What do you think of this quote: "They're a really iconic way to make people notice that you're trying to make a change in the community," What do you know about Mantua Tulips and the Mural Arts program?* (Ms. Lee, Lesson Plan Iteration 3, Engage)

In both discussions of the articles, Hard-working beauty (Tortorello, 2012) and the Mantua Tulips and the Mural Arts program (Romero, 2017), describe urban garden initiatives in terms of the social impacts (e.g. beautification of the community) and neglected the scientific concepts of the lesson (e.g. carbon footprint reduction, sustainability). This excerpt also included links to two separate articles relating to urban gardening projects and the environmental and spiritual impacts they had on those involved in said projects. Because Ms. Lee crafted a lesson plan in which an SSI was implicitly stated and translated, and because she engaged students in the SSI by reviewing primary sources and real-world examples, her lesson plan was scored a Level 2 in the area of *A. Identifying an issue*; had Ms. Lee been able to make her SSI explicitly debatable, they would have scored a Level 3 in this area.

In addition to *A. Identify the issue* that focuses on the social aspects of SSI, Ms. Lee's lesson plan also showed high levels of sophistication with respect to *D. Consider issue system dynamics* and *F. Compare and contrast multiple perspectives*, coded as a Level 3 and a Level 2 in those areas, respectively. Throughout the lesson plan, Ms. Lee incorporated economic, health, nature and equity *D. issue system dynamics* by asking students to consider, "What are the impacts of your crops on: Nutrition, Environmental, Ecological, Social, Free choice." Additionally, Ms. Lee incorporated the perspectives of public opinion and environmental activists into their lesson plan through the incorporated readings, mentioned earlier, that students were asked to reflect upon. Taken together, Ms. Lee composite score was a 7 in the social aspects of SSI.

At the same time, Ms. Lee showed low levels of sophistication in terms of the scientific aspects of SSI. Our analysis suggests that there was no explicit scientific phenomenon discussed, which resulted in a code of Level 0 for both *B-1. knowledge of scientific phenomenon* and *B-2. PCK of scientific phenomenon.* As we mentioned above in the example asking students to discuss the Hard-working beauty (Tortorello, 2012) and the Mantua Tulips and the Mural Arts program (Moreno, 2017), the teacher did not incorporate a scientific phenomenon such as plant growth and considering the challenges of sustainability.

Despite the lack of a described *B. scientific phenomenon*, Ms. Lee did include elements of Level 2 *C.* STEM modeling. From her lesson plan:

> *Individually students will use their own neighborhood data to derive how many acres of available land there is to plant crops. Students will calculate the amount of crop production potential in their neighborhood and will combine with the rest of the class to estimate [our city's]net growth.* (Ms. Lee, Lesson Plan 3, Elaborate)

From this excerpt of Ms. Lee's lesson plan, we can see that students are using neighborhood data to develop a model that describes the amount of land in their neighborhood that can be used for gardening. Students are then combining their data with others in the class to make predictions, specifically the amount of land in all of a city in the northeastern USA available for gardening. Because Ms. Lee's lesson plan shows students developing models and using these models to make predictions, they scored a Level 2 in the area of *C. STEM modeling*. Taken together with the other scientific codes, Ms. Lee ended up with an overall composite score of 2 for the scientific aspects of SSI, which was much lower than their composite score of a 7 for the social aspects of SSI. This suggests to us that Ms. Lee, along with 18 other teachers, struggled to balance their focus on the social and scientific aspects of SSI, particularly in that they focused primarily on the social, as opposed to the scientific, aspects of SSI in their lesson plans.

One final point of interest with respect to our second finding is that, despite the overall higher average scores in social aspects of SSI when compared with scores in scientific aspects of SSI, Figure 1 suggests that our teachers showed more growth from Lesson Plan Iteration 1 to Lesson Plan Iteration 3 in the scientific aspects of their SSI lesson plans. This is due in large part to the fact, as Figure 3 shows, that most teachers, on average, scored much higher on one of the social codes, *A. Identifying the issue*, than any other code at the beginning of the intensive series, as evidenced by their Lesson Plan Iteration 1. Aside from that code, teacher growth in the rest of the social codes was comparable to the growth they showed with the scientific codes in their lesson plans: in terms of growth scores, the top two social codes, *D. consider issue system dynamics* and *F. compare and contrast multiple perspectives*, show an average growth score of 1.7, and the top two scientific codes, *B-2. PCK of scientific phenomenon* and *C. STEM modeling*, show an average growth score of 1.6. Therefore, these findings still suggest to us that teachers focused more on the social aspects of the SSI than on the scientific aspects of the SSI in their lesson plans.

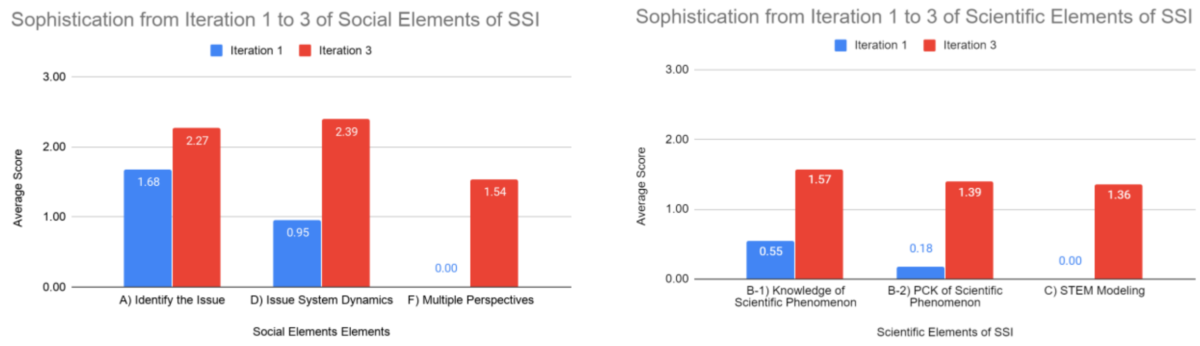

Figure 3. Changes in Sophistication of Social and Scientific Elements of SSI

Finding 3: Teachers Struggle with the Discursive Nature of SSI

The discursive nature of SSI involves two elements: *E. Employing reflective scientific skepticism* and *G. Elucidating one's position/solution*. Our results suggest that only 14% of teachers (n=4) exhibited statements and questions of a discursive nature in Lesson Plan Iteration 3, which was less than in other elements evaluated in our study. As it was stated, overall the growth for two discursive SSI elements was small. These showed small positive changes in our teachers' knowledge and implementation of SSI. This suggests that teachers struggled with the discursive nature of SSI. Considering the degree of this, only one teacher reached Level 1 and only one reached a Level 2 for *E. employing reflective scientific skepticism*. The two teachers, who were successful, framed students' entries into this element through strategic use of statements and questions, steering students to reexamine their source of information while studying the SSI. For example, Mr. Roberts used the following statement with, and posed the following question to students studying the controversy surrounding GMOs being used in public school lunch menus. *"When doing your research think about where you are getting your research from,"* and he goes on to ask, *"Who will gain little or no benefit from GMOs?"* (Mr. Roberts, Lesson Plan 3). Mr. Roberts presented information on GMOs and included a context prior to questioning his/her students. Likewise, Mr. Claitt poses this question in his/her GMO lesson *"How reliable is this method of sampling public opinion?"* Mr. Roberts presents this question as he guides students through the SSI content whose scientific phenomenon is centered on GMOs. Leading up to his/her question, Mr. Roberts refers to students in an online article in which students are asked to weigh in on the opinions. Mr. Roberts says,

> *"Have students review the Viewpoints: Harvest of Fear document. Ask them to describe each of the viewpoints introduced. Discuss the following: What concerns do you have about the issues raised? How can all these experts be right?"*

This leads into developing reflective scientific skepticism through the question posed *"How reliable is this* *method of sampling public opinion?"* because students are prompted to consider amongst other things, how these opinions were solicited. This is a legitimate question because the opinions came from people who had viewed the PBS Online (2001) program (described in more detail in Finding 1) on GMOs, and after viewing, the respondents could choose to have their opinion posted or not posted. Reflective scientific skepticism should question the reliability of the sample, especially in light of the fact that the sample of respondents could be skewed in one way or another.

These two teachers approached the discursive nature of SSI in different ways: Mr. Roberts did this by addressing from where the information was being disseminated and who is advantaged or disadvantaged within the context of the SSI [components b and d, Table 6], while Mr. Claitt embedded the discursive nature of SSI by prompting students to question the methodology of collecting feedback [component c, Table 6]. Both, however, met the criteria because they asked the students to question the author or organization disseminating the information, those who are disadvantaged/advantaged with respect to the SSI, and the purpose and/or methodology for obtaining information, respectively. Conversely, the majority of our teachers (89%, n=25) did not include *E. employing reflective scientific skepticism* in Lesson Plan Iteration 3. This suggests that teachers did not place emphasis on this particular SSI element while planning their lessons, perhaps because they were more focused on other SSI elements.

It is important to note that while we saw teachers posed questions that had the potential to meet the requirements of *E. employing reflective scientific skepticism*, they fell short by not asking questions that led students to assess biases, purpose, or background of the authors. For example, Mr. Minaj and Ms. Greene mentioned in their lesson plan *"As a member of City Council, you will be asked to pick a side of this issue and create a presentation on it to influence the rest of the Council. Back it up using research from the internet."* In this example, the teachers failed to connect or ask their students to question the sources of information they encounter. In another example, from the same lesson plan, *"How can we make this issue more important to more people your age?"* Mr. Minaj and Ms. Greene tried to engage their students to reflect on the issue of water usage based on their peer group, but did not include the question of who benefits or is disadvantaged from the lesson of water usage.

The second discursive SSI element provides a window for students to communicate their understanding of the SSI. The graph in Figure 4 reveals that more teachers (61%, n=17) included components of *G. Elucidate one's own position/solution* in their lesson plan than they did for *E. Employing scientific skepticism* (11%, n=3). Teachers showed an average growth score of 0.53 points in the discursive nature of SSI over the course of the intensive workshop series and, while we consider this to be a small change, this does show that teachers made some growth in this area of their SSI lesson plans. In teachers initial lesson plans, only four teachers included instructional strategies designed to *elucidate the positions or solutions* of students, although it should be noted that these four teachers were all a part of the same group and, for Lesson Plan Iteration 1, worked together to create one group lesson plan. In their lesson plan, they state, *"Using evidence-based and research-based data, what is ethical when making GMO food? What are scientists doing to make an organism? How is it ethical? Support your reasoning using mathematics or science knowledge."* This task calls on students to make a claim and support it with evidence, which was one of the components of students *elucidating their own position or solution*, and so this lesson plan was rated a one for this area.

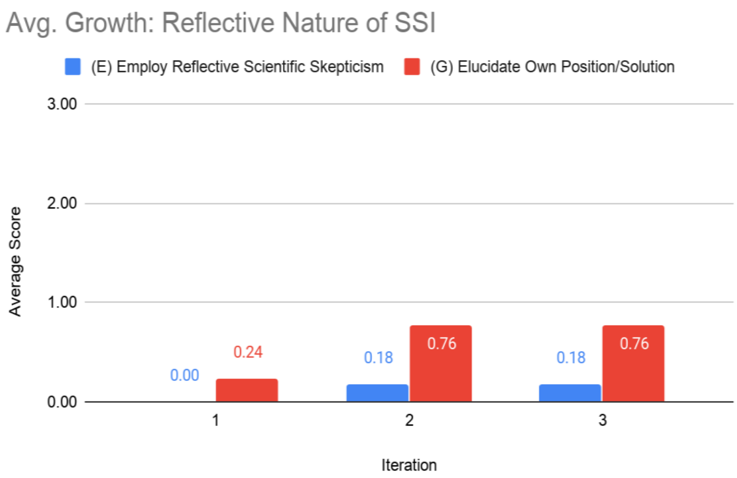

Figure 4. Average Lesson Plan Growth in Discursive Nature of SSI

In later Lesson Plan Iterations, more teachers (n=16) scored a Level 1 in the area of *elucidating their own position/solution*, and one teacher, Ms. Fefeti, scored a Level 2. In Ms. Fefeti's Lesson Plan Iteration 3, she wrote:

> *At this point students will be split into two groups. A pro GMO side and an Anti GMO side. Each group will be tasked with building a case with evidence for why their side is correct. They may use the arguments from the previous activities website, but they must back up their arguments with research and stats that they find on their own. For example if they are going to argue that GMOs have lead to death in rodent studies, they need to find a study in which that finding was shown to support that argument.*
>
> *Students from each side will make their case for why their stance is correct. The opposing group will write them feedback as they are presenting their proposal.*
>
> *They will look at the feedback and see how they can improve their arguments. [emphasis added] Then they will switch.* (Ms. Fefeti, Lesson Plan Iteration 3, Elaborate and Evaluate)

This excerpt shows that students are being given an opportunity to use data, in the form of research studies, to support their claims regarding the safety of genetically modified organisms (GMOs). Additionally, Ms. Fefeti had students evaluate the strengths and weaknesses of their claims through the instructional strategy of peer feedback. For these reasons, Ms. Fefeti's lesson plan was rated as a Level 2 in this category. If Ms. Fefeti had also asked students to reflect specifically on their own biases and the limitations of their claim, their lesson plan would have been rated as a Level 3. The nuance regarding the discursive nature of SSI embedded in this code will be elaborated on further in our third finding.

Discussion

Current science education reforms, and the framework of SSI, requires teachers to teach in ways that are fundamentally different from their own experiences learning science (e.g., Marco-Bujosa, McNeill et al., 2017; Berland et al., 2016). Shifting instruction to SSI represents significant epistemological and pedagogical changes in science instruction (Bayram-Jacobs et al., 2019; Macalalag et al., 2019) in order to effectively engage students in the complexity of interdisciplinary thinking necessary in SSI instruction. Our findings helped us to answer our research questions: 1) In what ways, if any, did teachers' knowledge and instructional design of SSI change throughout the intensive series of workshops based on their lesson plans? 2) What areas of SSI required additional support?

Overall, we found that teachers demonstrated learning with respect to both the scientific and social elements of SSI (see Finding 1), which indicates that the SSI framework promotes more traditional science conceptual knowledge and PCK alongside the new SSI elements. However, teachers placed a greater emphasis on the social elements of SSI, indicating a need to attain a balance in the focus of their instruction in SSI lessons (see Finding 2). Finally, teachers struggled to incorporate the more discursive elements of SSI (see Finding 3), indicating teachers may need additional support and practice with these elements of the SSI framework. Given the goals of this study were to understand how teacher learning about SSI was supported (or not) from their experiences in the PD, the findings of this study are discussed relative to the two areas of PCK in which teachers need the most support for designing and implementing SSI lessons (orientations toward science and instructional strategies) and the aspects of the PD workshop series that supported teacher learning.

PCK and SSI

Pedagogical content knowledge represents the transformation of content knowledge integrated with a teacher's knowledge of pedagogy and context. Specifically, there is a need for more research about PCK related to specific science topics, and how PCK of specific topics influences instructional practice (Magnusson et al., 1999). The findings of this study contribute to the research base on pedagogical context knowledge for teaching SSI and illuminates the complex interactions between different components of PCK (Bayrum-Jacobs et al., 2019).

Previous research has found teacher learning about SSI could be supported through supporting teachers making strong interconnections between instructional goals, anticipating challenges in student understanding, acquiring instructional and assessment strategies, and focusing equally on science content and SSI skills (Bayrum-Jacobs et al., 2019). The findings of our present study focused more specifically on the elements of SSI, and illustrated the PCK involved in implementing these components in the context of instructional design for SSI. Findings illustrate how the participants in this study did or did not grow in these domains. Specifically, two domains of PCK emerged as central to designing SSI lessons that integrated the scientific, social, and discursive elements of SSI: orientations toward science teaching, which reflected the centrality their personal and curricular goals as science teachers in their pedagogical choices; and their beliefs and knowledge of instructional strategies that would develop student conceptual understanding and skills related to SSI elements.

Orientations toward Science Teaching

Teaching science and mathematics through the SSI framework extends beyond the study of nature and technology by extending to consider content through the lens of real-world issues, explicitly considering the political, moral, cultural, and ethical aspects of the problem (Zeidler, 2016), as well as topics of citizenship (Barrue & Albe, 2013) and values (Lee et al., 2013) not typically addressed in a STEM classroom. Orientations toward science and science teaching influence the instructional goals teachers establish in the classroom, and therefore influence other domains of PCK (Magnusson et al., 1999). The teachers in this study successfully designed lessons that provided a real-world context for students to engage in the scientific and social dimensions inherent in SSI lessons. For example, study participants designed lessons in which students considered local environmental concerns, such as urban gardening, as well as topics such as recycling plastic bottles. Perhaps paradoxically, the findings indicated teachers exhibited greater growth in the social dimensions of SSI than the scientific dimensions (see Finding 2). These scores indicated teachers addressed the SSI through a greater complexity of social elements, including engaging students in considering social dynamics around the science issue through political, economic, ethical, and religious perspectives (see Figures 2 & 3).

Comparing findings across these dimensions illustrates that teachers' orientations toward science, and their beliefs, mindsets, and values about how to teach science was shifting after participating in the SSI PD. This finding indicates the PD was able to challenge teachers' orientations toward science. Many teachers typically view science as factual and objective (see Figures 2 & 3). Their orientations toward science served as a "conceptual map" guiding instructional decisions and preferences including instructional objectives, activities, and how student learning is assessed (Borko & Putnam, 1996), with teachers often emphasizing the memorization of facts and the more procedural elements of the discipline (Ekborg, Margareta, et al. 2012; Gray & Bryce, 2006). The findings indicate that participating in the SSI PD supported teachers in shifting their instruction to emphasize the more social and dynamic elements of science, as indicated by greater growth gains in the social elements of the SSI framework (e.g. *A. Identifying the issue* and *F. Compare and contrast multiple perspectives*) as compared to the more scientific elements (e.g. *B. Scientific phenomenon* and *C. Engage in STEM modeling,* Figures 2 & 3).

While teachers developed PCK in integrating the social and scientific elements, they struggled to employ scientific skepticism in their lessons. For example, lesson plans did not engage students questioning the source of information in terms of biases, purpose, or background of the authors in conducting research about the SSI. This finding indicates that while they were broadening the scope of science instruction to delve into the complexity of real-world, social dynamics, they still did not emphasize students questioning and critiquing scientific sources to identify biases, one aspect of development for students in SSI that is critically lacking (Wineburg, et al., 2016). Therefore, teachers still maintained their prior scientific habits of mind reflecting the objectivity of science. This finding aligns with other research indicating that these scientific habits of mind are deeply rooted and difficult to change, even through PD (e.g., Ekborg, Margareta, et al., 2012; Gray & Bryce, 2006). More work is needed to develop their PCK to implement the discursive elements of SSI and argumentation, such as *E. Employ reflective scientific skepticism* and *G. Elucidate own position/solution* into their lesson plans (Dolan et al., 2009; Marco-Bujosa, González-Howard et al., 2017).

Instructional Strategies

Magnusson and colleagues (1999) identified teacher knowledge and beliefs of instructional strategies for teaching science as a central component of teacher PCK. They delineated two distinct but related strands of instructional knowledge, which they referred to as subject specific strategies and topic specific strategies. Subject-specific strategies are broadly applicable; they are specific to teaching science as opposed to other subjects. Topic-specific strategies are much narrower in scope; they apply to teaching particular topics within a domain of science. (p. 15)

SSI specifically falls within the realm of topic-specific strategies, and encompasses particular representations, including models, teachers utilize to convey a scientific phenomenon or ideas, and activities to support student conceptual understanding. Selection of appropriate instructional strategies is essential to teaching SSI. Teachers must be able to create a classroom environment and select appropriate teaching methods in order 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). SSI differs greatly from more traditional, didactic teacher-centered approaches to teaching science. For example, in order to show growth in the scientific phenomenon, the teacher must provide opportunities for students to observe and explain the scientific phenomenon, while also providing real-world examples.

Participating teachers exhibited the greatest knowledge gains in the following four components of SSI that reflect the two components of topic-specific instructional strategies: *B-2. PCK of scientific phenomenon*, *C. STEM modeling*, *D. issue system dynamics*, and *F. comparing and contrasting multiple perspectives*. First, with STEM modeling, participating teachers utilized a variety of models and activities in their lesson plans addressing STEM content. This indicates increased knowledge of instructional strategies to support student engagement in these SSI elements. Effective engagement of students with scientific modeling, an important pedagogical tool, can also pose a challenge for teachers (Stammen, et al. 2018). The rubric for STEM modeling ranges from teacher use to student use of models, and reflects increasing student agency. Effectively using modeling in SSI lessons reflects an increase in PCK. As discussed by Magnusson and colleagues (1999),"knowing or inventing representations of science concepts to help students comprehend them seems necessarily dependent upon having subject matter knowledge relative to the concepts" (p. 17). For example, Ms. Washington engaged students in modeling to transport their GMO plants into outer space. In the context of space travel, students utilized scientific knowledge about the forces associated with rocket launch and landing during space travel in order to make predictions and revise their models. This illustrates Ms. Washington's ability to engage her students in scientific modeling, including the use of scientific concepts, applied to a fantastic and engaging real-world context.

In addition to *B-2. PCK of STEM modeling*, lesson plans provide students with opportunities to *D. Consider issue system dynamics*. "Pedagogical content knowledge of this type also includes teachers' knowledge of the conceptual power of a particular activity; that is, the extent to which an activity presents, signals, or clarifies important information about a specific concept or relationship" (Magnusson et al., 1999, p. 18). For example, Ms. Rodriguez provides links to a variety of videos and news articles that explore the various dimensions of the topic of water quality, including public health, government regulation and politics, economics, and equity. Utilizing this variety of perspectives to explore one topic highlight her PCK of instructional strategies to clarify the dynamics of the issue for students.

Teachers' Lesson Design Based on Workshop Content

Promoting growth in teachers' PCK of SSI, specifically changing their orientations toward science and their knowledge of instructional strategies, was supported in the PD workshop series. The PD featured best practices in PD to support teacher learning. For example, the PD offered a distinct vision of effective practice and provided opportunities to increase their understanding of teaching and learning, and modeled the desired practice (e.g. introductory session, informational workshops) (Darling Hammond & McLaughlin, 1995; Louchs-Horsley, et al. 1998). This modeling promoted teacher learning and to shift their teaching away from more traditional methods of teaching mathematics and science toward SSI.

Second, the PD was sustained over five months. The sustained nature of the PD supported teacher learning of SSI in several ways. First, it allowed teachers to consider the social issues in depth, reflecting both on their instructional practice, the social dynamics of the science issue, and on their students' needs (Hancock, Friedrichsen, Kinslow & Sadler, 2019). The sustained nature of the PD also provided teachers with the opportunity to apply what they learned in their classroom and to reflect on the process of instructional design (Darling Hammond and McLaughlin, 1995; Louchs-Horsley, et al. 1998), through planned cycles of lesson planning and revision, and encouraged teachers to adopt an inquiry stance toward their instruction (Cochran-Smith & Lytle, 1999).

Third, our initial analysis of lesson plans developed by our teachers (Minken, Macalalag & Richardson, 2020) allowed us to narrow and guide the focus of our subsequent PD. In particular, we saw the need for teachers to incorporate *F. Compare and contrast multiple perspectives* in their lessons. As a result, we developed and provided a PD allowing teachers to evaluate perspectives from various stakeholders. Specifically, teachers worked in small groups at their tables, and picked the role of a stakeholder from an envelope that they used to navigate the activity on gene editing (scientific phenomenon). Based on their assigned perspective, teachers found pros and cons of gene editing individually using the Socioscientific Argument Outline (Appendix C) before discussing their individual findings with similar stakeholder groups, and then finally with members of different stakeholder perspectives.

Furthermore, collaboration among teachers, specifically group lesson planning, was a central component of teacher learning Over the duration of the PD, collaborative groups of teachers were provided time to grapple with the development of shared meaning and understandings about an issue (Hancock, Friedrichsen, Kinslow & Sadler, 2019) as well as their instructional practice (Cochran-Smith & Lytle, 1999). Group lesson planning as part of PD has shown to positively impact teachers' thinking, intentions and actions around SSI teaching. In a prior study, Minken et al. (2020) found teachers who engaged in collaborative lesson design for SSI included more than half of the SSI components such as scientific phenomena, system dynamics, social, political, and cultural aspects of the unit of study (Minken et al., 2020). Having sustained PD about SSI has also been linked to improvements in teacher ability to identify SSI issues to connect to the curriculum, improvements in teacher ability to make sophisticated and detailed connections between the science content and the social issue, and deeper reflection on the affordances and challenges of addressing orientations toward science in SSI instruction (Leden et al., 2007).

The PD also placed an emphasis on teacher learning of new pedagogical strategies within the context of rich content (Jeanpierre et al., 2005), which modeled instructional strategies and engaged teachers in learning science through SSI. Engaging in professional development experiences that position the teacher as the learner has been found effective in other science PD introducing new instructional frameworks, notably the science practices (Marco-Bujosa, González-Howard et al., 2017; Lowell & McNeill, 2020). The opportunity to engage in instructional activities as a learner is important because most science teachers did not have the opportunity to learn science in this way (Osborne, 2014). The student perspective allows them to get in the mindset of the student and to understand the power of the SSI framework to promote deep student learning.

For example, one of the Waste Not, Want Not: Reducing Food Waste Through STEM and Civic Engagement, the workshop activities engaged teachers as learners in a sample mathematics SSI activity to experience the different elements of SSI. In order to *A. Identify the issue*, teachers addressed ways in which students could use math to calculate the amount of money wasted due to school lunch items that go uneaten, winding up in the trash. Teachers were able to *C. Engage in STEM modeling*, components of developing models, and using these models to convey information and make predictions by analyzing collected food waste data from a specific school, calculating the amount of money wasted as a result, and then developing a sustainability plan for eliminating the waste, and reinvesting the wasted money in other resources for their school. In terms of *G. Elucidate own position/solution*, teachers described their plan to present to the local school board as well as local businesses. Moreover, participants were tasked with calculating how much food waste was costing their school district and coming up with a proposal for how to repurpose that money in sustainable ways. Teachers then incorporated elements of this model SSI lesson into their lesson plans, illustrating growth in A. Identify the issue, C. Engage in STEM modeling, and G. Elucidate own position/solution.

While these workshop elements seemed to be supportive of teacher learning about the scientific and social elements of SSI, teachers' change in scientific skepticism was less evident. It is possible that scientific skepticism is the more challenging element of SSI, as it is grounded in teachers' orientations toward science and habits of mind, which are deeply rooted in the field of science, society, and science education. Different types of learning experience than those offered in these workshops may be required to force teachers to confront these often implicit beliefs about the teaching and learning of science that guide instructional design. It is also possible that a longer time frame is needed to shift teachers' orientations to science enough to integrate scientific skepticism into their instructional design efforts. For example, Leden et al. (2007) engaged teachers in a three year PD about SSI and found teachers were able to adequately incorporate orientations about science into their instruction. The limited change in scientific skepticism may also reflect a mismatch between the goals of the PD and teacher beliefs, which has been identified as an obstacle to teacher learning in other research in science education (Marco-Bujosa, González-Howard et al., 2017; Jeanpierre et al., 2005).

Conclusion

Our investigation is centered on the following research questions: 1) In what ways, if any, did teachers' knowledge and instructional design of SSI change throughout the intensive series of workshops based on their lesson plans? 2) What areas of SSI required additional support? Our analysis of lesson plans developed by 29 teachers suggested the successes and challenges of our teachers while incorporating the elements of SSI in their lesson plans. Providing learning experiences to help teachers plan and implement lessons using SSI takes time, PD to support teachers is needed, and a personal professional investment by teachers to acquire the PCK necessary to support student learning (Hancock et al., 2019; Leden et al., 2007). In order to effectively plan SSI lessons, teachers must develop pedagogical content knowledge (PCK) specific to unpacking elements of SSI such as identifying an issue that is controversial or debatable and relevant to students' lives, employing reflective scientific skepticism, and evaluating multiple perspectives. Our PD provided numerous opportunities for teachers to experience SSI activities themselves, during the kickoff conference and intensive workshops, and to develop their own PCK as they iteratively plan their lessons with other teachers and mentors.

Our findings suggest teachers demonstrated positive changes in all SSI elements over the course of their PD. Teacher lesson plans showed the most growth in the following elements of SSI: *B-2. PCK of scientific phenomenon*, *C. STEM modeling*, *D. consider issue system dynamics*, and *F. compare and contrast multiple perspectives* (Finding 1). This suggests that teachers focused more on the development of these SSI elements than on others in their lesson plan. However, deeper analysis reveals that teachers struggled to balance the social and scientific aspects of SSI (Finding 2). Specifically, the majority of teachers incorporated more social aspects than scientific aspects of SSI in their lesson plans. This suggests that most teachers, despite showing similar growth in these elements, had a more developed PCK of the social elements of SSI than of the scientific elements of SSI by the end of the third workshop. Moreover, our analysis of data suggests that teachers did not focus on the discursive nature of SSI in their lesson plans (Finding 3). While the majority of teachers were able to incorporate both social and scientific aspects of SSI at some level of sophistication, our data suggests that few teachers incorporated discursive aspects of SSI into their lesson plans.

Implications of our study include ways in which PD programs can cultivate teachers' PCK of SSI in order to better support them in planning and implementing SSI lessons. In future studies, researchers should explore ways to extend the time for PD, with a focus on STEM modeling and discursive practices. More research is needed on using SSI to engage students in STEM beyond scientific literacy to incorporate elements of technological and mathematical literacy through attributes of the engineering design processes, problem solving, and model development to study patterns and predict behavior. Finally, teachers may be able to better engage students in the discursive nature of SSI by challenging their students to systematically question established norms and belief systems (e.g. inequality, systemic racism) of various societal structures.

Limitations of Study

There are limitations to this study. While lesson plans offer insight to teacher PCK based upon their instructional decisions, PCK is also directly linked to classroom practice and is highly contextualized (Schneider & Plasman, 2011). Therefore, future research should draw upon observations of instruction or artifacts of instruction (activities, assessments, student work) to assess this knowledge. Also, while participants in this study mostly taught science or mathematics at the secondary level, a few elementary teachers participated (Table 3). While we utilized the same coding scheme to evaluate their lessons with respect to PCK of SSI, there were likely variations in instruction at each grade level, due to child development and background content knowledge, that would influence how students engage in SSI in each grade level. Our instrumentation was not able to detect these differences.

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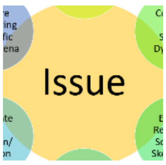
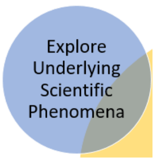
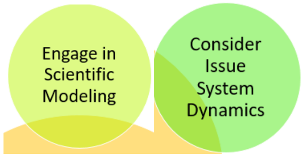
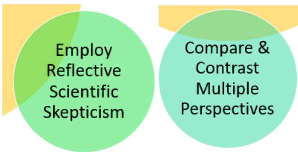
Appendix A. Lesson Plan Template

<table>
<tr><td>Grade/ Grade Band:</td><td>Topic:</td><td>Lesson # _____ in a series of _____ lessons</td></tr>
<tr><td colspan="3">Brief Unit Description: List Big ideas covered in the unit.</td></tr>
<tr><td colspan="3">Brief Lesson Description:</td></tr>
<tr><td colspan="3">Description and Explanation of SSI:</td></tr>
<tr><td colspan="3">Specific Learning Outcomes:</td></tr>
<tr><td colspan="3">Narrative / Background Information</td></tr>
<tr><td colspan="3">Prior Student Knowledge:</td></tr>
<tr><td>Science and Engineering Practices</td><td>Disciplinary Core Ideas:</td><td>Crosscutting Concepts:</td></tr>
<tr><td colspan="3">Possible Preconceptions/Misconceptions:</td></tr>
<tr><td colspan="3">Standards: Education for Sustainability and PA Core/Eligible Content</td></tr>
<tr><td colspan="3"> LESSON PLAN</td></tr>
<tr><td colspan="3">ENGAGE: Establish relevancy - help learner determine need of learning new concepts
</td></tr>
<tr><td colspan="3">EXPLORE: Present the content - help learner understand concepts, process/procedures, facts or principles
</td></tr>
</table>

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



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



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

Elaborate Further / Reflect: Enrichment:

Appendix B. Sample Lesson

Lesson Plan: Buying a Car: Free Choice or Government Regulation

Victor Donnay, November 22, 2019

Essential Question: How do our choices of cars impact the environment?
Should gov't have a say in which choices we are able to make or should we have free choice in making our choices?

Engage:	You have won a lucky ticket to purchase any type of car you want? What type of car would you choose? What features do you want?
Explore	Teams of 4: each team explores the features of one car. In this mock lesson, much of the information has already been researched for the team. There are guided inquiry questions focusing on the gas mileage of the car, the amount of gas the car uses in a year, the cost of the gas and then the carbon footprint of the car. (Q1-3).
Explain	We explore the connection between the carbon footprint of a car, our own personal carbon footprint and the rising C02 levels globally. Then groups do (Q4-6). We examine a variety of potential government interventions: higher fuel efficiency standards, raising the taxes of gasoline.
Elaborate	Teams of 4: Research the impacts of government regulation and argue based on this evidence whether the government should impose these restrictions and why. a. Brainstorm a concept map of potential impacts of various regulations b. Examine the implications of "business as usual" c. Use math formulas to investigate outcomes of different scenarios.
Evaluate	Ask the participants: What would you want to assess in a lesson like this and how would you do it? Examples: - As a government official, what policy would you set and how would you justify it? - Write an op-ed letter to newspaper or government official outlining and justifying your position - Etc.

Handouts:

1. Vehicle Choice: Features and Impacts
2. Elaborate: Research the impacts of government regulation.

Appendix C. Socioscientific Argument Outline

Socioscientific Argument Outline- *for Human Genome Editing Lesson*

* keep in mind that socioscientific arguments may have no clear right or wrong, but you can still pick a side to argue based on science evidence as well as your personal opinion or ethics

Topic (explain or define terms as needed)

Claim

My opinion or viewpoint on this topic is….

Other viewpoints/ counterarguments

____
____
____
____
____
____
____

Weaknesses with these views are …

____
____
____
____
____
____

Evidence

1. ____
____
____
____

Source:

2. ____
____
____
____

Source:

3. ____
____
____
____

Source:

(add more on back if needed)

Reasoning (Final ideas that relate to my claim and evidence)

Appendix D. Coding Guide

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

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).		
Level 3	**Level 2**	**Level 1**
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	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	Lesson plan contains: a) **Debatable SSI explicitly or implicitly stated** and translated in the lesson
<u>Example</u>: "Does inclusion of ingredients from genetically modified organisms make inherently food [sic] unsafe, dangerous or unhealthy?" --**Mr. Claitt**, Description and Explanation of SSI section, [component a] "If time allows, have teams look at seed catalogs to identify two food plants and the specific different	**<u>Example</u>**: "Identify what asbestos is, where asbestos can be found, and why it can be dangerous *in order to* document by means of a multimedia presentation the current situation of asbestos exposure in schools" **--Ms. Diamond,** component a (implicit: how does asbestos affect you?), [component c]	**<u>Example</u>**: "How, if at all, might GMOs affect space travel and sustained human life during space exploration? Under what conditions would GMO research have utility? What is the cost benefit analysis one must do when getting funding for scientific endeavors?" -- **Ms. Washington**, component a (<u>implicit</u>: not clearly debatable)

characteristics for which they have been bred. Then show the Bt Corn video so students can compare how plants are being genetically modified by new technologies. In pairs, have students discuss whether or not they think corn should be genetically modified and why." -- **Mr. Claitt**, Engage section, [component b]		
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		
Level 3	**Level 2**	**Level 1**
All three 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	Only two 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	One component: a) Explicit **naming** of the anchor phenomenon
Example: "...various ramifications that plastic water bottles have. This will include looking at the life cycle of plastic" [component a] [Videos] What really happens to the plastic you throw away - Emma Bryce & Lifecycle of a Plastic Water Bottle [component b] "We have watched two videos	**Example**: "Students will be given a guided note sheet, ...forces acting on a body in space, as well as the history and definition of GMOs." [component a] "...create GMOs that will blunt some of the effects of space travel on plants" [component c] **--Ms. Washington**	**Example**: This unit will cover factors which affect plant growth (nature of light, key wavelengths, important chemical reactions and products synthesized by plants **--Ms. Rosario**

about the life cycle of plastic bottles...Are there things we can do individually or collectively that could help with our current situation?" [component c] -- **Mr. Banks**		
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	Only <u>two</u> components: a) teacher relates anchor scientific phenomenon or mathematical system to students' everyday experiences	<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	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	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
Example: "Show the Classical vs. Transgenic Breeding video [component b] Then discuss examples of plants that have been traditionally bred for certain characteristics (e.g., firmer or sweeter tomatoes, wilt-resistant cucumbers, etc.). If time allows, have teams look at seed catalogs [component a] to identify two food plants and the specific different characteristics for which they have been bred. Then show the Bt Corn video so students can compare how plants are being genetically modified by new technologies. In pairs, have students discuss whether or not they think corn should be genetically modified and why. Have students do the Engineer a Crop: Transgenic Manipulation Web activities [component c], including both 'Selective Breeding' and 'Transgenic Manipulation.' Then, as a class, discuss the similarities and differences between selective breeding and transgenic manipulation." -- **Mr. Claitt**	**Example**: "Show this video. This video is a great introduction to what GMOs even are. https://whyy.pbslearningmedia.org/asset/tdc02_vid_breeding/ " -- **Ms. Fefeti**, [components a and b]	Example: "Students will complete a guided investigation activity. This activity will have them compare the genetic sequences of different pairs of people without knowing their ethnicities. After comparing, students will try to determine if the pairs of people are from similar or different ethnicities. After students complete the activity, the truth will be revealed as to whether their determinations were correct. This will open up discussions and hopefully change some students' thinking." -- **Mr. Morita**, [component c]

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**
Three or four 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	Two 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	One 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
Example: "How many plastic cups or plastic bottles did we use in the last week? [component c] Do you think there are any other options?.... How much plastic did we use this week? How many weeks are in a year? [component a] How many plastic products do you think we might use in a year? [component d]	**Example**: "Students will first use water testing kits to see the contents of each type of water we are testing (Poland Springs, Deerpark, Aquafina, and tap water). Students will use their science notebooks to graph and chart the data from the experiments they are conducting. [component a] Students will create a table in their science notebooks that details the contents of each sample.	**Example**: "How food is grown and produced including pesticides and herbicides, impact on people, farmers, land, and water resources https://www.terrapass.com/carbon-footprint-calculator carbon footprint calculation, politics of access to food/produce" -- **Ms. Streit** [component c]

We have figured out an estimate of how much plastic our classroom uses during the school year [component a]. Do we think that is too much? Now let's put that in perspective of the whole school. How many classrooms do we have [component a]? How much do you think the WHOLE school uses?[component d]" --**Mr. Banks**, components a, c, and d	We will refer to our original sample, of what constitutes as "good" or drinkable water. Students will then work in groups to assess data, and determine which "types" or brands of water are the most drinkable, and if there are any discernible differences between different brands, and overall against tap water. [component c]" -- **Mr. Romero & Ms. Davies**	
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**
<u>Four or more</u> components: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity	<u>Two or three</u> components: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity	<u>One</u> component: a) political b) cultural c) economic d) ethical e) religious f) health g) nature h) equity
<u>Example</u>: "Introduce the <u>discussion</u> section of the Harvest of Fear Web site, which includes viewers' comments on the entire [GMO] program. Tell students you have divided up the section so that each team can analyze a portion of this public	**Example**: "Teacher will introduce the activity. Students will be given a budget for space exploration. Their task will be to either create GMOs that will blunt some of the effects of space travel on plants, OR create conditions that will allow non-	**Example**: "What is asbestos? Where is it used? Is it dangerous? Why? When? How much exposure can we tolerate?" -- **Ms. Diamond**, [component f]

opinion data." -- **Mr. Claitt**; *website includes viewpoints that consider political, economic, ethical, religious, health, and nature issues*	GMO plants to thrive. They will need to consider budget, environmental impact, and forces unique to interstellar travel. Students will write proposals justifying their plans." -- **Ms. Washington**	
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	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

respect to the SSI		
Example: [Not Found]	Example: When doing your research think about where you are getting your research from [component b] Who will gain little or no benefit from GMOs? [component c] --**Mr. Roberts**	**Example**: “Have each team identify in their batch of comments the arguments for and against genetic modification of food. Then have them list the pros and cons in separate columns on a sheet of paper. Next, have each team report to the class the number of contributors who are for and against GM foods. Finally, record the results in a class chart on the board. When finished, discuss the following: ● What are the results? ● How have viewers' comments influenced students' opinions? ● How reliable is this method of sampling public opinion? ● What are some ways in which more random data might be collected?” -- **Mr. Claitt**, [component c]
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	Two or three perspectives: a) media b) scientists c) businesses d) politicians e) researchers f) public opinion	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) political groups h) religious organizations i) environmental activists	f) public opinion g) political groups h) religious organizations i) environmental activists
Example: "Ask students to examine the Should We Grow GM Crops? Web activity. Discuss how they voted and which arguments most influenced their decision." -- **Mr. Claitt (1)**, *website with statements/viewpoints from scientists, political groups, politicians, environmental activists* "Show the Super Salmon video. Ask: What allows transgenic salmon to grow in winter? What are some possible consequences if transgenic salmon escape from their pens into the ocean population? How might transgenic salmon affect the evolution of other salmon populations? Do you think the FDA should give Aquabounty permission to grow and sell transgenic salmon? Why or why not?" -- **Mr. Claitt (1)** "Students will select (or be assigned(a side to debate GMO foods in regards to: Should we make them or not? Should they be required to be labeled? SHould private companies be allowed to patent foods?"-- **Mr.**	**Example**: "Students will look at the pros and cons of food deserts from the perspective of a resident of the area, a food business owner (grocery store, fast food chain) and a policy maker (council person or representative)" -- **Mr. Kowalski**	Example: School Trip (Bartram Gardens; "Corner Store"; Lancaster, PA--Sunflower Farm; Community Garden; et al) [component c] -- **Ms. Rosario**

Claitt (1)		
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.
Example: [Not Found]	Example: "Students from each side will make their case for why their stance is correct. The opposing group will write them feedback as they are presenting their proposal. They will look at the feedback and see how they can improve their arguments. Then they will switch. In this way, students will become more prepared for their final project." -- **Ms. Fefeti**, [components a and b]	Example: "Choose a claim and defend using evidence from today's lesson and the provided documents" -- **Mr. Morita,** [component a]