Spring 5-16-2024

Teaching STEM for Social Justice: An Exploration and Analysis of Teachers’ Pedagogical Content Knowledge

Zachary Minken
Arcadia University, zminken@gmail.com

Teaching STEM for Social Justice: An Exploration and Analysis of Teachers' Pedagogical Content Knowledge

Arcadia University

Ed.D. Program in Educational Leadership

Zachary A. Minken

A DISSERTATION

IN

EDUCATION

Presented to the Faculties of Arcadia University in Partial Fulfillment of the
Requirements for the Degree of Doctor of Education

2024

Approved and recommended for acceptance as a dissertation in partial fulfillment of the requirements of Doctor of Education.

4/22/2024

[Defense Date]

Special Committee directing the doctoral work of Zachary Minken

---

Chair: Dr. Augusto Z. Macalalag Jr.. Ed.D.

Associate Professor, Arcadia University

Committee Member: Dr. Foram Bukhanwala, Ph.D.

Associate Professor, Arcadia University

Committee Member: Dr. Greer Richardson, Ph.D.

Professor, LaSalle University

Abstract

Research Problem

Reforms in Science, Technology, Engineering, and Mathematics education over the past several decades have resulted in a somewhat steady pressure to infuse personal, social, and cultural relevance into STEM education (DeBoer, 1991; Gallagher, 1971; Hekimoglu & Sloan, 2005; ITEEA, 1996, 2020; NCTM, 2000; NRC, 1989, 2009, 2010, 2012). This emphasis on relevance eventually resulted in a push for social justice in education as a means to both engage learners and to develop students' moral and ethical reasoning abilities in hopes that this would lead to a more just world (Dos Santos, 2009; Zeidler, 2016). Amidst rising concerns for relevant and equitable curricula, socioscientific issues (SSI) can be seen as an avenue to provide STEM teaching through a more justice-centered approach (Dos Santos, 2009; Morales-Doyle, 2017). However, engaging in social justice pedagogies in general is not always easy for teachers, and often underexplored for STEM teachers in particular (Kokka, 2018). For instance, teachers often struggle with implementing SSI due to issues with time constraints, confidence, and support (Fadzil, 2017; Saunders & Rennie, 2013).

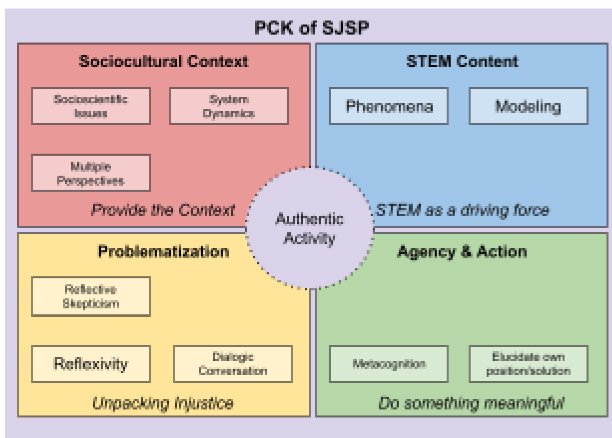
Conceptual Framework: PCK of Social Justice STEM Pedagogy

Pedagogical content knowledge (PCK) can be a useful model for describing and analyzing the different facets of teacher knowledge involved in successfully planning for and implementing classroom instruction (Gess-Newsome, 2015; Shulman, 1986). Important in understanding PCK are both the different pools of teacher knowledge contained within PCK (e.g. Magnusson et al., 1999; Chang & Park, 2020), and a holistic understanding of the context-specific particularities of teacher knowledge (Gess-Newsome, 2015). This study will use PCK of Social Justice STEM Pedagogy (SJSP) as a conceptual framework for understanding how teachers can teach STEM for social justice. This PCK of SJSP Framework (Figure 1) organizes instruction around an

authentic, organizing SSI and is used to embed STEM content within sociocultural contexts relevant to students' lives (Minken et al., 2020, 2021; Sadler et al., 2019; Zeidler, 2016). Through exploration of this SSI, the teacher is able to reframe the SSI as related to issues of injustice through problematization (Dos Santos, 2009; Freire, 1970/2000; Morales-Doyle, 2017, 2020) and develop students agency and move them to act in order to help resolve the issues of injustice revealed by the SSI (Dimick, 2012; Rodriguez, 1998; Sadler et al., 2019).

Figure 1

Pedagogical Content Knowledge of Social Justice STEM Pedagogy



Research Methods

This study used a case study design (Creswell & Poth, 2018; Yin, 2018) to explore the ways teachers in the J-STEM program develop and conceptualize their Pedagogical Content Knowledge (PCK) relating to Social Justice STEM Pedagogy (SJSP). Specifically, this study explored the ways in which teachers participating in the J-STEM program developed and refined their pedagogical content knowledge of SJSP throughout the course of the program. This study was guided by the following research questions:

RQ1: To what extent did teachers adapt their PCK of SJSP in the (re)development of a unit of study?

RQ2: To what extent did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom?

RQ3: To what extent were teachers' PCK of SJSP similar and different as they (re)developed a unit of study?

In this case, all of the research questions were focused on the PCK of SJSP for teachers participating in the J-STEM program. Therefore, the case under investigation was identified as the development of secondary teachers' PCK of SJSP in the context of the J-STEM Program. This constitutes what Creswell and Poth (2018) refer to as an intrinsic case, as it "presents an unusual or unique situation" (p. 99) where teachers of STEM subjects are engaging in structured professional learning centered around infusing social justice into STEM. Bounding the case is important in deciding how to focus the case, such that there is clarity between what constitutes the case and what constitutes the context thereof. This case was bounded to the experiences and perceptions of teachers in the inaugural cohort that relate to the development of their PCK of SJSP. Other participants, staff, program activities, etc. were seen as the context within which the case resides. Three of these teachers were enrolled as participants in this study. All three are white, veteran teachers with more than 10 years of teaching experience teaching in public schools in low-income neighborhoods. Mr. Rubin is male, while Ms. Rossi and Ms. Moretti are female. Ms. Moretti and Mr. Rubin taught 6th grade science, while Ms. Rossi taught 11th & 12th grade physics and chemistry. None of these teachers had experience teaching with SSI prior to joining the J-STEM program.

Findings and Conclusion

Teachers in this study expressed PCK of Authentic Activity throughout their SJSP unit of study, showing that they sought to make learning authentic while they incorporated each of the additional four SJSP domains consecutively. Teachers did this by incorporating and valuing student voice, making learning relevant to their students, and engaging community partners throughout their units of study. Regardless of the order they chose in moving through the framework, the teachers expressed their PCK of Sociocultural Context by engaging students in exploring socioscientific issues, and analyzing these issues through multiple perspectives, and expressed their PCK of STEM Content through their use of modeling and through the ways in which they had students collect and analyze data. After guiding their students through the STEM Content and Sociocultural Context relevant to the SJSP unit of study, teachers engaged students in problematizing the underlying SSI. Teachers in this study expressed their PCK of Problematization in a variety of ways, including engaging students in reflecting on the relationship between the perspectives people have based on their backgrounds and experiences (reflexivity) and engaging in meaningful dialogue around these varied perspectives and implications relative to the SSI (dialogic conversation). Teachers further expressed their PCK of Problematization in the way they illuminated tensions inherent in the SSI central to their SJSP unit of study by asking students to consider how implications of the SSI and potential resolutions thereof would play out on a local vs. a global scale (magnification), and furthermore how the particulars of the SSI shifted depending on the locale the SSI was applied to (comparative localization). Finally, teachers built on students’ capacity to problematize the SSI, surfacing issues of injustice, to cultivate students’ Agency and support them in Action related to resolving the SSI. Teachers expressed this PCK of Agency & Action through the ways they had students

elucidate their own positions and solutions with respect to the SSI and by engaging students in community improvement projects. In extending student learning beyond the walls of the classroom, teachers seemed to primarily emphasize the importance of community improvement projects. Teachers' PCK of SJSP differed in the ways in which they emphasized different domains. Implications, limitations, and directions for future research are discussed.

Acknowledgements

I would like to acknowledge everyone who helped and supported me through the doctoral process. First and foremost, my beautiful wife, Athena Phoenix, who helped convince me to start this crazy doctoral journey in the first place, and supported me all the way through. I truly could not have made it here without you.

Dr. Augusto Macalalag, for being the best dissertation chair I could have asked for. Your feedback pushed me to be a better writer, even when I complained about it! You were always willing to help me take a step back and consider the bigger picture, and guided me through the minutiae of turning a book report into a literature review. I will always remember the first day we met, when I hoped to talk to you about my dissertation, and ended up walking out of your office with a stack of survey data to analyze for our very first publication!

To the additional members of my dissertation committee: Dr. Foram Bukhanwala and Dr. Greer Richardson. Thank you for your willingness to provide me with critical feedback to improve the quality of my study. You both pushed me to make my dissertation better.

To my doctoral professors, thank you for teaching me and helping me to understand some of the more nuanced aspects of research. And to all the members of my cohort, who made those weekly Thursday night classes fun and memorable, even when we were all tired and just wanted to go home! In particular, I would like to give a special thanks to Andre Clarke, Dr. Charu Varma, Dr. Julie Dunphy, and Johanna Cella. Working together with all of you and talking out various struggles with our dissertations made this long process go much faster. I learned a lot from each one of you.

I would like to thank all of the J-STEM Teachers and Staff who made J-STEM a truly one of a kind program. I thoroughly enjoyed working with each and everyone of you. A special thank you to Dr. Joseph Johnson, Dr. Becky Mathers, and Dr. Lisa Marco-Bujosa, who challenged me to think through our research more deeply. And to our amazing research assistants, in particular Gabrielle Ialacci and Marlin Marte who worked tirelessly to help transcribe and code much of the data used in our J-STEM projects. Working with you helped me tremendously in making sense of our research data.

I would also like to thank all of my colleagues in the schools where I have worked who took an interest in my research and convinced me to keep going. In particular, Paula Miller, Micah Reyes, and Najah Naylor who helped me to think through SSI in practical applications, and helped me to become a better educator. Additionally, I would like to thank Andrew Boglioli, Tiffaney Whipple, Aileen Burr, Richard Sherin, Jeniffer Lennon, Kristian Ali, and Dr. Jeanine Payne, who supported my growth as an educator in immeasurable ways.

Finally, this material is based upon work supported by the National Science Foundation under Grant No. 2101395. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

Dedication

I would like to dedicate this work to all of my students, who made my time in the classroom so much more meaningful. Teaching you challenged me to think deeply and differently about the purpose and value of STEM education. Truly, I became a better educator because of you. I would also like to dedicate this work to all of the STEM educators working tirelessly every day to make this a better world for the young people in front of you.

Table of Contents

List of Appendices

List of Tables

List of Figures

Chapter 1: Introduction

Since the turn of the past century, our society has become increasingly more dependent upon advances in science, technology, engineering and mathematics (STEM), yet the understanding of STEM concepts held by the general populace has not kept pace with these advancements (DeBoer, 1991; National Research Council [NRC], 2006, 2009). All too often, STEM has been abstracted from daily life. In other words, while the general public is very much aware of all of the scientific and technological advancements they use and benefit from (e.g., smartphones, laptops, and wifi), they often use these technologies without understanding how they work, or even seeing a reason why they should (International Technology and Engineering Educators Association [ITEEA], 1996). At the same time, the general public is impacted by, and must make decisions around, issues often rooted in scientific and mathematical principles, such as vaccination mandates, population growth, and controlling greenhouse gas emissions (Driver et al., 1996). Successful resolution of these issues of societal relevance and scientific significance, often called socioscientific issues (SSIs), depend on a STEM literate society, meaning that members of society must be able to use and "apply…STEM concepts and skills to provide solutions for STEM-related personal, societal, and global challenges that cannot be solved using a single discipline" (Mohr-Schroeder, 2020, p. 33). As such, national reform movements in STEM education over the past several decades have sought to both integrate these disciplines and to make STEM education more relevant to students in order to develop students' STEM literacy skills (American Association for the Advancement of Science [AAAS], 1990; Common Core State Standards Initiative [CCSSI], 2010; ITEEA 1996, 2020; National Academies of Sciences, Engineering, and Medicine [NASEM], 2019; National Council of Teachers of Mathematics [NCTM], 2000; NRC, 1989, 1996; 2012; National Science Teachers Association

[NSTA], 1982). More recently, there have been calls to infuse social justice into STEM education in order to empower learners (Dimick, 2012) and to make the content more engaging (Kolstø, 2001; Rodriguez & Berryman, 2002) while building students' STEM literacy skills through moral and ethical reasoning (Johnson et al., in press; Kinskey & Zeidler, 2021; Owens & Sadler, 2020; Zeidler, 2016). In order for teachers to be able to teach in such a way that answers this call, they need to have knowledge not just of STEM content and social justice, but also knowledge of how to teach STEM content for social justice. This type of knowledge is referred to in the literature as pedagogical content knowledge (PCK; Gess-Newsome, 1999, 2015; Magnusson et al., 1999; Shulman 1986).

The purpose of this study was to explore the ways in which secondary teachers of STEM subjects adapt and express their PCK of STEM to teach STEM for social justice. While there is much research that supports and calls for the incorporation of social justice themes in STEM education (Aikenhead, 1985; Garibay, 2015; Kokka, 2018; Morales-Doyle, 2020; Rodriguez, 1998; Zeidler, 2016), this has proven both difficult to do in practice (Dimick, 2012), and underexplored in the research base (Brown et al., 2019; Mensah, 2011; Morales-Doyle, 2017). In this chapter, I will provide background of the study, outline the research problem, describe the context of the study, and articulate the rationale for and significance of this dissertation research study.

Background of the Study

In order to provide background knowledge needed for a clearer understanding of this dissertation study, I will provide a brief overview of both STEM education and Socioscientific Issues.

STEM Education

The term STEM was initially used by the National Science Foundation in the 1990s as a way of concisely naming the four constituent disciplines of Science, Technology, Engineering, and Mathematics (Bybee, 2013). Although the term STEM has come to have a somewhat ambiguous definition since that point (Bybee, 2013), it is now commonly used to refer to an integrated approach to education within the constituent STEM subjects, often with the focus of developing analytical reasoning and problem solving skills, or what has been described as STEM literacy (Mohr-Schroeder et al., 2020). While there are a multitude of ways to approach STEM literacy in the classroom, the use of SSIs as organizing constructs for a unit of study within a STEM course has been shown to be an effective means of achieving this goal (Owens & Sadler, 2020).

Socioscientific Issues Education

Socioscientific Issues (SSIs) can be thought of as both a specific issue (Driver et al., 1996), and framework for contextualizing STEM content in relevant, societal issues (Sadler et al., 2019). As a specific issue, an SSI represents an issue of societal relevance associated with, though not fully resolved by, STEM (Driver et al., 1996). Further, SSIs are often conceived as "open-ended, ill-structured problems which are typically contentious and subject to multiple perspectives and solutions" (Sadler & Zeidler, 2005b, p. 72). As a framework, SSI is a way of using issues of societal and scientific relevance to cultivate students' STEM literacy skills (Owens & Sadler, 2020; Sadler et al., 2019; Zeidler et al., 2011). The framework promulgated by Sadler et al. (2019) involves the idea of centering instructional activities in which students explore scientific phenomena, engage in STEM modeling, consider social systems that interact with STEM content, compare and contrast multiple perspectives, and practice skepticism with regard to where information is coming from, all centered around a particular SSI as a focal issue. Minken et al. (2021) have further categorized these activities as comprising different social, scientific, and discursive domains of the SSI framework. As a framework, SSI can be seen as a culmination of pushes for relevance in STEM curricula, such as the Science-Technology-Society (STS) movement from the 1970s, which was geared toward illuminating the symbiotic relationships between science, technology and society (Gallagher, 1971; Hurd, 1975), and extending them to include a focus on moral and ethical reasoning (Zeidler et al., 2005).

Research Problem

National guidance in STEM education recommends students engage in solving real-world problems related to STEM content, and that educational experiences in STEM are accessible and equitable for all learners, specifically those belonging to historically marginalized groups and groups underrepresented in STEM fields (NGSS Lead States, 2013). However, in practice, many teachers' pedagogical approaches throughout the country have not kept pace with this guidance (NASEM, 2019). Social Justice STEM Pedagogy (SJSP) is one way that teachers can support all learners in cultivating STEM literacy. SJSP organizes instruction around an authentic, organizing SSI, and is used to embed STEM content within sociocultural contexts relevant to students' lives (Minken et al., 2020; Minken et al., 2021; Sadler et al., 2019; Zeidler, 2016). Through exploration of this SSI, the teacher is able to reframe the SSI as related to issues of injustice through problematization (Dos Santos, 2009; Freire, 1970/2000; Morales-Doyle, 2017, 2020), and develop students agency and move them to act in order to help resolve the issues of injustice revealed by the SSI (Dimick, 2012; Rodriguez, 1998; Sadler et al., 2019). However, developing and implementing SJSP units of study can be challenging for teachers across all areas of SJSP: *authenticity*, *STEM content*, *sociocultural context*, *problematization*, and *agency & action*.

Authenticity

While important, authentic STEM learning experiences that support and promote an integrated STEM literacy for the purposes of informed decision making and full participation in a democratic society are not common in K–12 schools (Mohr-Schroeder et al., 2020). STEM Teachers don't often use curricula or plan lessons that are authentic and relatable to their students (Mohr-Schroeder et al., 2020). Instead, many use pre-packaged curricula from textbooks or other commercially developed sources (NASEM, 2019). Holbrook and Rannikmae (2009) suggest that successfully promoting scientific literacy for students depends on making science curriculum relevant for students due to the propensity for relevance to inspire intrinsic motivation of students in science. However, they also note "that students do not find knowledge taught to be useful in their future and everyday life" (Holbrook & Rannikmae, 2009, p. 285).

Sociocultural Contexts

Despite a pervasive focus in STEM on problem solving, STEM content is frequently taught in a vacuum, artificially separated from society and societal values that are important considerations in problem-solving (Holbrook & Rannikmae, 2017). STEM teachers rarely incorporate sociocultural contexts into their lessons (Magee et al., 2020), often due to a lack of preparedness to do so (Brown et al., 2019). When they do attempt to incorporate sociocultural contexts in their STEM lessons, many teachers experience difficulties such as those involving shifting their mindset, cultural misunderstandings, and failing to address their own cultural biases (Olayemi & DeBoer, 2021). Additionally, teachers' sometimes have difficulty in using the sociocultural context of the SSI to frame it as a debatable or controversial issue (Minken et al., 2021), which can make it more difficult to problematize. Teachers developing lessons that incorporated SSI often did not plan activities that involved students comparing and contrasting multiple perspectives (Minken et al., 2020), an essential practice for resolving SSIs (Sadler et al., 2019).

STEM Content

STEM teachers often engage in more didactic, teacher-centered pedagogical practices (NASEM, 2019), despite national calls for inquiry and student-centered approaches (CCSSI, 2010; ITEEA, 2020; NGSS Lead States, 2013). This is often due to issues such as lack of time and confidence needed to implement scientific inquiry (Guzey et al., 2020). When teachers are able to implement more of these reform-driven approaches to teaching STEM, they often struggle with designing and using assessments that capture the students' STEM literacy (Cian et al., 2019). Furthermore, teachers' capacity to design and implement learning activities that make use of STEM modeling is often underdeveloped (Sadler et al., 2019). Additionally, teachers are frequently not prepared to integrate different STEM content, such as engineering design, in their teaching practice (Crotty et al., 2017).

Problematization

When teachers do incorporate sociocultural contexts as a driving focus of the lesson, the lesson often fails to acknowledge issues of injustice baked into socioscientific issues, and instead serve to perpetuate the status quo (Morales-Doyle, 2020). Teachers are often surprised to learn, and find it difficult "to move beyond the typical *neutral*, *apolitical* stance in science and actively address oppression" (Boutte & Kelly-Jackson, 2010, p. 11). In fact, social justice, both in general and with respect to STEM, is a frequently ignored concept in educational practice and literature (Madden et al., 2017). This is sometimes due to lack of teachers' comfort, confidence, and preparedness to address these issues in the classroom (Boutte & Kelly-Jackson, 2010). Additionally, teachers are often unfamiliar with the type of reasoning necessary to recognize and reconcile issues of injustice related to sociocultural contexts and STEM content (Sadler et al., 2019).

Agency & Action

Examples of teaching STEM in ways that engage students in social justice projects that imbue them with the confidence to address such issues outside of the classroom, and provide scaffolding to support them in doing so, are few and far between (Boutte & Kelly-Jackson, 2010; Dimick, 2012; Morales-Doyle, 2017). Furthermore, these lessons are not always successful, such as instances in which teachers' fail to connect and build relationships with their students, or otherwise impose their own erroneous, preconceived notions of students' abilities and motivations (e.g., Tobin, 2002). Sometimes, as Dimick (2012) found, teachers plan lessons that empower students to be change agents in a scientific context, but do so at the expense of teaching STEM content. In fact, more evidence is needed to show how classroom activities can help build students' agency, especially with respect to out of school activities (Gutstein, 2007).

This dissertation study will focus on how teachers can address these issues through the use of Social Justice STEM Pedagogy (elaborated in chapter 2), with a particular focus on the ways in which teachers problematize socioscientific issues and cultivate students agency and capacity to act outside the classroom with respect to said socioscientific issue.

Context of the Study

This study used a case study design (Creswell & Poth, 2018; Yin, 2018) to explore the ways teachers in the J-STEM program develop and conceptualize their PCK relating to SJSP. Specifically, this study explored the ways in which teachers participating in the J-STEM program developed and refined their pedagogical content knowledge of SJSP throughout the course of the program. It is worth noting that, although STEM provides a relevant context for this study, the participants in this study were teachers of science, and not necessarily engaging in integrated STEM. However, these teachers are still considered STEM teachers, and analyzing their PCK will still provide a rich understanding of PCK of SJSP. This study answered the following research questions:

1. RQ1: To what extent, if any, did teachers adapt their PCK of SJSP in the (re)development of a unit of study?
2. RQ2: To what extent, if any, did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom?
3. RQ3: To what extent, if any, were teachers' PCK of SJSP similar and different as they (re)developed a unit of study?

In this case, all of the research questions were focused on the PCK of SJSP for teachers participating in the J-STEM program. Therefore, the case under investigation was identified as the development of secondary teachers' PCK of SJSP in the context of the J-STEM Program. This constitutes what Creswell and Poth (2018) refer to as an intrinsic case, as it "presents an unusual or unique situation" (p. 99) where teachers of STEM subjects are engaging in structured professional learning centered around infusing social justice into STEM. Bounding the case is important in deciding how to focus the case, such that there is clarity between what constitutes the case and what constitutes the context thereof. This case was bounded to the experiences and perceptions of teachers in the inaugural cohort that relate to the development of their PCK of SJSP. Other participants, staff, program activities, etc. are seen as the context within which the case resides. Three of these teachers were enrolled as participants in this study. All three are white, veteran teachers with more than 10 years of teaching experience teaching in public schools in low-income neighborhoods. Mr. Rubin is male, while Ms. Rossi and Ms. Moretti are female. Ms. Moretti and Mr. Rubin taught 6th grade science, while Ms. Rossi taught 11th & 12th grade physics and chemistry. None of these teachers had experience teaching with SSI prior to joining the J-STEM program.

Rationale for and Significance of the Study

While social justice STEM pedagogies can be useful for cultivating students' STEM literacy skills, teachers often struggle to implement this type of instructional approach (Fadzil, 2017; Saunders & Rennie, 2013). Additionally, there are few examples of SJSP in the literature (Boutte & Kelly-Jackson, 2010; Dimick, 2012; Morales-Doyle, 2017). As such, there is a need to better understand the pedagogical content knowledge teachers need to successfully plan and implement SJSP lessons. This study served to explore and analyze teachers' PCK of SJSP, thus providing more examples of what PCK of SJSP looks like, and what PCK is needed to plan SJSP lessons. Additionally, the findings of this study helped to add to the theoretical understandings of PCK of SJSP, an important consideration given that social justice pedagogical approaches are undertheorized in STEM education (Brown et al., 2019; Madden et al., 2017; Mensah, 2011; Morales-Doyle, 2017).

Conclusion

In this chapter, I have introduced the topics of STEM and socioscientific issues (SSI) in education, and how these two constructs intertwine to produce a social justice STEM pedagogy (SJSP) that is beneficial for development of STEM Literacy. I have also outlined the research problems related to teachers' struggles with different aspects of SJSP as seen in the literature base. In addition I have stated the research questions that guided this dissertation study, and provided an overview of the context of the study, along with its rationale and significance.

In the following chapter, I will engage in a deeper dive into the literature surrounding SJSP, including a brief history of STEM education, the ways in which SSI can be used to further students' STEM literacy, the construct of pedagogical content knowledge (PCK) and how it can be applied to STEM and SSI, and finally describe PCK of SJSP as a conceptual framework that was be used to guide this dissertation study.

Chapter 2: Review of the Literature

In this chapter, I will first outline a brief history of STEM education, from discrete disciplinary subjects to an integrated pedagogy, noting trends toward interdisciplinary pedagogical approaches and the shifts toward a more socioculturally relevant and inclusive pedagogy over time. Second, I will expand on a particular movement in STEM education, driven by the use of what have become known as socioscientific issues (Sadler et al., 2019; Zeidler et al., 2002; Zeidler et al., 2005), to position STEM content within sociocultural contexts that highlight issues of social controversy and societal injustice. Third, I will introduce the theoretical construct of pedagogical content knowledge (Gess-Newsome, 2015; Lee, 2016; Magnusson et al., 1999; Shulman, 1986) as a framework for understanding teachers' practitioner knowledge base associated with teaching STEM, before finally elaborating on a conceptual and pedagogical framework, and associated pedagogical content knowledge, for teaching STEM through the lens of social justice, which I call Social Justice STEM Pedagogy (Dimick, 2012; Dos Santos, 2009; Freire, 1970/2000; Gutstein, 2003; Ladson-Billings 1995a, 1995b; Mims, 2003; Morales-Doyle, 2017, 2020; NRC, 1999; Rodriguez, 1998; Sadler et al., 2019).

Brief history of STEM Education

In order to fully capture the importance and meaning of STEM Literacy in a culturally relevant context, it is helpful to first understand how the nature of STEM education has developed over time. In that regard, I will begin by exploring how the history of each individual STEM education subject led to the development of individual content literacies (i.e., science literacy, technology literacy, engineering literacy, and mathematics literacy). Then, I will show how the integration of these disciplines led to the development of integrated STEM literacies.

Science

According to DeBoer (1991), science education in the general K-12 curriculum emerged in the United States shortly before the turn of the 20th century as a way of increasing students' critical thinking skills and relating education more toward students' lives, as the country at that time was going through significant changes propelled by science and technology, including the development of the internal combustion engine and widespread use of telephones ("America at the turn of the century," n.d.). Over time, the push for science education became closely tied to laboratory investigations, societal relevance, and disciplinary structure (DeBoer, 1991).

At the turn of the 20th century, John Dewey developed a reform-oriented laboratory school based on, at the time, novel ideas in the United States educational system (Tanner, 1997). Dewey's laboratory school was holistic in its approach to education, as it combined elements of social interaction, such as play, and personal interest relevant to the students to create a cohesive learning environment that fostered creativity and critical thinking (Tanner, 1997). It was one of the first times that students' interests and the notion of societal relevance was incorporated, and often a driving force, in students' formal education. Another central theme of Dewey's laboratory school was, as the name might suggest, investigation and experimentation, both by the faculty and the students (Tanner, 1997). In Dewey's revolutionary new school, much of students' learning was as a result of their ability to construct knowledge from inquiries and investigations, sometimes through structured play in the earlier elementary grades, and often through investigations in the biological and physical science classes (Tanner, 1997). The idea, and purpose, of laboratory experiments, activities, and investigations became a central theme in science education over the latter half of the century, with many different viewpoints emerging on the purposes and effectiveness of investigations in science classes (NASEM, 2019; NRC, 2006).

For instance, Dewey argued that, while the use of investigations was important to science education, equally important was the purpose, as, according to Dewey, students would not learn nearly as much from step-by-step procedures designed to confirm a previously taught principle as they would through a more open ended investigation steeped in inquiry (NRC, 2006). This contrasting idea of using laboratory investigations to supplement content taught in class, or to confirm scientific laws and concepts already taught, describes the way in which the laboratory was often used in science classes at the time, and even today (NASEM, 2019; NRC, 2006). Initially, the use of a laboratory was an essential part of scientific investigations and activities in science class because it afforded students the opportunity to engage with hands-on materials and physically interact with and observe objects of scientific interest (NRC, 2006). However, over time the focus shifted to engaging students in different practices of science through the use of physical materials, data sets, and computer simulations, which lead to less emphasis on the laboratory itself, and more emphasis on the investigations in science education research (NASEM, 2019; NRC, 2012). It should be noted, however, that while the literature on science education has evolved to reflect this shift, many science classrooms around the country have not (NASEM, 2019).

Maintaining balance between societal relevance and core, foundational concepts in the sciences was the topic of much public debate around the purpose and goals of science education in much of the 20th century (DeBoer, 1991). Much of this debate was around the degree to which disciplinary structure, practical application, and cultural and historical context were emphasized in science education (NRC, 2006). Despite this tension, science education has steadily developed with a goal of being more socially relevant, notwithstanding some heavy criticism and backlash around the time of World War II (DeBoer, 1991). Shymansky et al. (1983) note a division in the goals and aims of science education in the United States before and after 1955, around the time of the Sputnik launch. According to Shymansky et al., the pre-1955 emphasis in science education was around what can be described as scientific trivia, such as significant "scientific facts, laws, theories, and applications" (p. 388), while post-1955 goals in science education centered more around science as a process. The push for more disciplinary structure in science came in part from a lack of technically qualified personnel during World War II and, later, the space race between the USA and Russia (DeBoer, 1991). It was argued that a more rigorous science education would better prepare the citizenry for competition with other nations (DeBoer, 1991). On the other hand, the declining enrollment and shortage of qualified scientists and engineers pointed to a lack of interest in science among the general public (DeBoer, 1991). This lack of interest likewise drove science educators to develop more socially and personally relevant curricula (DeBoer, 1991) that included a richer context to show how science could be used as a basis for decision making in everyday life (DeBoer, 2000). This played out in a number of interesting ways.

In 1971, James Gallagher articulated a framework for science teaching that "include[d] the conceptual and process dimensions of science along with their relation to technology and society" (p. 329), which has commonly come to be referred to as Science, Technology and Society (STS). Simply stated, this STS model of science teaching considers the interplay between science, technology, and society. As scientific knowledge progresses, so do technological applications that depend on these new scientific concepts. At the same time, new technological advances, such as radio telescopes and computers, make possible further advancements in scientific knowledge. All the while, these scientific and technological advances influence the direction of societal development, and society in turn influences the direction of scientific and technological development. Gallagher argued that this symbiosis in science, technology and society held important implications for reform in science teaching, namely that technology and society should be included in science courses in terms of their relation to science and to learner's everyday experiences. STS was an enormous departure from prior science education reform movements, requiring a paradigm shift for science educators (Aikenhead, 2003). According to Paul Hurd (1975), the STS movement was an attempt to, in the context of science education, integrate science and technology more clearly into society, and society into science and technology, in this way disposing of the artificial distinctions that separate humanity from the human activities of science and technology. STS goes beyond previous reform efforts in that the goals of laboratory investigations, societal relevance, and disciplinary structure are all synthesized in the STS approach such that, in science classes aligned to the STS framework, teachers would engage their pupils in both the process and content associated with scientific and technological concepts and applications that have direct connections to society (Gallagher, 1971). STS involves having students investigate science content and its applications through exploring socially relevant issues and topics in which that science is applied (Hurd, 1975). Aikenhead (1992) describes a pedagogical process for implementing STS in a science classroom. First, the teacher chooses a social context linked to students' everyday lives in which to anchor the science content that will be taught (Aikenhead, 1992). Through the examination of this social context, students will be guided to consider the various technological techniques and products associated with the context, and then engage with the scientific knowledge and skills relevant to that technology (Aikenhead, 1992). Once the students have mastered the necessary science content, the teacher will have students reconsider the different technologies that make use of said scientific understandings before finally re-examining the initial social context, through the lens of students' newly acquired scientific knowledge and skills (Aikenhead, 1992). In this way, STS provides a way for teachers to tackle all of these important goals in science education with a cohesive approach. While STS involves technology, it is defined primarily as the link between science and society (Hurd, 1975). In the STS framework, technology is defined as both the application of scientific concepts and processes (Gallagher, 1971), but also as its own discipline that influences the direction of scientific progress and development (Layton, 1988). According to Hurd (1975), the role of technology within STS is to provide a conduit between science and society, as technology is the means by which science affects and shapes society, and likewise through which society influences science. Although technology is commonly thought of as nothing more than an application of science and scientific thought, this is a gross oversimplification of technology, especially through STS (Aikenhead, 1992). While both science and technology are very much related, indeed the very concept of STS would be entirely incoherent were this not the case, they are both different and separate ways that people interact with their world (Aikenhead, 1992). In his description of STS, Kranzberg (1991) puts it very simply, stating "science is concerned with 'knowing why,' that is, comprehending underlying physical and natural principles, while technology is concerned with 'knowing how,' how to make and do things" (235). While it is important to understand both the why and the how, and understanding one can lead to a more informed understanding of the other, science and technology answer two fundamentally different questions (Aikenhead, 1992; Kranzberg 1991).

STS has been implemented in the classroom in a variety of ways, ranging from standalone courses integrating social issues with science content to additional reading passages provided in textbooks (Zeidler et al., 2005). In a study of STS implementation at a Canadian high school, Aikenhead (1984) found that chemistry and physics teachers tended to value quantitative reasoning and problem solving skills, emphasizing them almost exclusively on the tests and quizzes they used with their students. Integration of social contexts and discussion of applications of science content, on the other hand, were introduced as ways to spark and sustain student interest, but the extent to which students learned this information was not assessed by teachers on their tests and quizzes. According to Aikenhead, "if a teacher introduced a science-technology-society topic, for instance, primarily for motivational value, this content was not evaluated. It was usually treated as an interesting digression" (p. 178). These STS related digressions were used by teachers as a way to incorporate student interest, and to delve into areas outside of the prescribed curriculum that the teachers thought to be important and worthy of discussion and explanation (Aikenhead, 1984).

A decade later, in 1982, the National Science Teachers Association (NSTA) echoed this call for STS education in science classrooms, coming out with specific sets of recommendations for science education based on the STS approach for different grade levels of science education, including professional learning opportunities for science teachers. Additionally, the NSTA proposed a list of knowledge and skills that someone who is scientifically and technologically literate would be able to know and do. These included multiple items involving the interplay of STS, such as "understand[ing] that society controls science and technology through the allocation of resources," and "recogniz[ing] the limitations as well as the usefulness of science and technology in advancing human welfare" (NSTA, 1983, Declarations section).

In 1990, the AAAS issued a report entitled *Science for all Americans*, which called for developing all students' scientific literacy. According to the AAAS (1990), scientific literacy is knowing both about science and how to do science, as well as how to apply that knowledge in various settings. Key elements of scientific literacy put forth by AAAS "include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the science depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes." (para. 25) Scientific literacy can be exemplified both inside and outside of classroom settings. Inside the classroom, for example, scientifically literate students should be able to connect scientific knowledge and skills to real-world contexts such as agriculture, and be able to make well-reasoned claims based on scientific evidence gathered from a classroom science investigation. Examples of scientific literacy outside of the classroom, include correct use of scientific terms (NRC, 1996), as well as critiquing and evaluating arguments based on scientific reasoning. The *Science for all Americans* report was notable for a number of reasons. One of which was the strong emphasis on the word "all" in this publication, which was an attempt to push for equity in science instruction. Another involved the interplay of science with technology, mathematics, and society inherent in AAAS's interpretation of scientific literacy, which appears to build on the STS movement that began to pick up speed a decade earlier.

Shortly thereafter, The National Science Education Standards (NSES) of 1996 were released in order to provide more guidance on the ways that students' scientific literacy should be developed in K-12 education. The NSES emphasized the relevance of science and scientific literacy to a changing job market where more technical and scientific skills were necessary to remain competitive in a global economy (NRC, 1996). They defined scientific literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (p. 22), and provided more specifics in the different grade level standards they released. Science teaching according to the NSES involved both hands-on and minds-on activities that enabled students to learn science by doing science. This stood in contrast to certain previous approaches to science teaching that focused on memorization of specific science facts (DeBoer, 1991). Instead, the NSES called for development of students' scientific literacy skills through the process of inquiry, which requires that "students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others" (NRC, 1996, p. 2). This type of inquiry was both similar and different from previous conceptions of the term, mainly in its purpose (DeBoer, 2000). Previously, inquiry in science education served as a means for students to develop independent, critical thinking skills in the 1800s, and then as a way for students to develop an appreciation for science as an enterprise because inquiry was seen as a reflection of the way practicing scientists carried out their work (Deboer, 2000). With the NSES, the purpose of inquiry in science education was to cultivate students' scientific literacy skills (NRC, 1996). Within the NSES, the term inquiry itself is used to refer to different abilities students should develop, such as planning and carrying out scientific investigations, knowledge about how scientists learn new things, as well as ways of teaching (NRC, 2000; Shapiro & Kraus, 2022).

After another decade, the NRC released *America's Lab Report*, a review of the importance and purpose of laboratory experiences in K-12 science education. In this report, the NRC (2006) defined scientific literacy as "the basic understanding of science that [people] need to make informed decisions about the many scientific issues affecting their lives" (p. 1). They also note the contradiction between the nation's apparent understanding of the importance of foundational scientific literacy for the general public and the stagnant and declining scores of secondary students on science assessments included in the National Assessment of Educational Progress (NAEP). In this context, they describe the role of laboratory activities in secondary science classrooms in developing students' scientific literacy, and evaluate the effectiveness of such activities. They listed the following goals of student laboratory activities: "enhancing mastery of subject matter; developing scientific reasoning; understanding the complexity and ambiguity of empirical work' developing practical skills; understanding the nature of science; cultivating interest in science and interest in learning science; and developing teamwork abilities" (p. 3). The NRC found that, while lab activities can be helpful in developing students' scientific literacy skills, some barriers include teachers' preparedness to effectively run a science laboratory activity, state standards that emphasize multitudinous concepts in a singular course, proper assessment of laboratory experiences, and "the organization and structure of most high schools" (p. 8). According to the NRC, in order to best realize the goals of high school science laboratories, the following four criteria must be met: "They are designed with clear learning outcome in mind," "They are thoroughly sequenced into the flow of classroom science instruction," "They are designed to integrate learning of science content with learning about the processes of science," and "They incorporate ongoing student reflection and discussion" (p. 6). In order for laboratory investigations to be effective, they must be clearly tied to an objective, and that objective must be communicated to students in a manner they find comprehensible (NRC, 2006). That purpose could be to gather evidence that supports the 2:1 ratio of Hydrogen to Oxygen in an electrolysis of water experiment, or to show how different traits in birds make them more or less suited to a given environment, or any other purpose so long as it can be communicated clearly to students; no specific purpose is demonstrably better than another so long as the communication of said purpose is clear (NRC, 2006). Effective laboratory investigations must be properly integrated into a given instructional unit (NRC, 2006). Although many teachers incorporate laboratory investigations into their curriculum as a standalone or isolated activity, this is a subpar approach for building students' knowledge and skills in science; investigations that tie in more directly into an instructional sequence in ways that build on prior knowledge and enable students to reflect on unanticipated experimental outcomes that can be addressed in follow up lessons provide for a much fuller and more effective laboratory experience for students in science classrooms (NRC, 2006). Not only are laboratory experiences made effective through their integration into instructional units, they are also made effective when they are crafted such that science content students are exploring can be intertwined with scientific processes that students are engaging in (NRC, 2006). For example, students might engage with the science content of learning the parts of the cell by engaging with the scientific process of making careful observations using a microscope. Finally, laboratory investigations are effective when they stimulate reflection and discussion surrounding scientific content and processes (NRC, 2006). To do this, teachers might encourage students to form tentative explanations for observed phenomena prior to a laboratory investigation, and then evaluate this explanation after collecting data as a part of the investigation (NRC, 2006). In this way, students are using the laboratory investigation as a way of testing out ideas, generating data that they can use to support their conclusions and arguments.

More recently, In 2012, the NRC put out a new guiding document for science education entitled *A Framework for K-12 Science Teaching: Practices, Crosscutting Concepts, and Core Ideas*. This new vision for science education attempted to address what has historically been seen as competing needs: providing a satisfactory science education for both future scientists and engineers, and for those who will likely not pursue a career in such fields (DeBoer, 1991; NRC, 2012). In doing so, they attempted to provide more coherence in science education by integrating *disciplinary core ideas* (DCIs) with *science and engineering practices* (SEPs) and *crosscutting concepts* (CCs) into classroom teaching practices. The DCIs of the NGSS are similar in scope to the NSES, but the emphasis on the SEPs and CCs represent a shift in thinking about the focus of science education (Bybee, 2014). While the previous focus of standards primarily centered around the content students were responsible for learning, the NGSS exemplify the shift in education toward a more integrated focus on content and process advocated for in *America's Lab Report* (NRC, 2006). Even though integration of content and process through inquiry was espoused through both the NSES and the NGSS, this integration was not often seen in state standards based around the NSES: while inquiry was included, it was often as a separate set of standards. In contrast, because development of the NGSS was a state-lead effort, the NGSS standards adopted by the states retained much of the original intent and spirit of integrating content with process through inquiry as described in the Framework for K-12 Science Teaching (Pruitt, 2014).

In this way, they propose a shift away from students simply learning *about* science to learning how to *do* science. It should be noted that, although this framework discusses science, technology, and engineering in education, they do so primarily in the context of science education, where engineering and technology are incorporated as a means to further the study of science. This guidance was later standardized in the form of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013).

Technology

According to de Vries (2018), technology education began as a sort of crafting and/or vocational/technical education that took hold during the Industrial Revolution. Since then, technology education has evolved through the Science Technology in Society (STS) movement and the related development and promulgation of the idea of technological literacy, and technology as applied science. De Vries contends that the STEM movement further elevated the importance of technology education, although its thorough integration into STEM lessons has not been without difficulty.

In the publication *Technology for All Americans*, the International Technology Educators Association (ITEA; 1996), describes the importance of technology as it relates to other fields and disciplines, in particular to society and the environment, as well as mathematics and the sciences: society informs technological needs, and in turn new technologies shape the way that society progresses. As new technologies are produced and used, they have differing impacts on the environment. There is a similar symbiotic relationship between science and mathematics and technology, as technology depends on understandings of various scientific and mathematical laws and principles, and the development of new technologies can further pursuits in science and mathematics. In this way, ITEA notes the interconnectedness of technology with science and mathematics. This idea is similar to that presented in the earlier publication, *Science for all Americans*, by the AAAS (1990), in that both reports espouse the important relationships between the disciplines of science, technology, and mathematics, and with society in general; a theme from the STS movement decades prior. While early conceptions of STS sometimes position technology as merely a bridge that links science to society (see Hurd, 1975), the symbiosis pointed to by the ITEA (1996) and AAAS (1990) positions technology as more than just a means to an end. Rather, technology should be thought of as its own unique discipline, existing both in relation to, yet independent from, disciplines such as science and mathematics (Layton, 1988).

A point at which the ideas promulgated by the ITEEA (formerly ITEA; 1996) and AAAS (1990) diverge, however, can be seen in the way both organizations chose to define disciplinary literacy. ITEEA (ITEA, 1996) defined technological literacy as “the ability to use, manage, and understand technology” (p. 6). In this sense, using technology means being able to use various technological systems and understand their parts and how they behave. Managing technology means being able to determine and assess these technological systems in terms of efficiency and appropriateness, and understanding technology means being able to form new insights from a variety of information about technology. While the guiding document espouses an interconnected, STS approach to technology education, similar to how AAAS (1990) espoused this approach for science education, ITEA’s technological literacy revolves solely around the discipline of technology. This is in contrast to the AAAS (1990) description of scientific literacy as depending on a rich understanding of the interplay inherent in STS.

Another interesting and recent development in technology education came in 2020 when the ITEEA (formerly ITEA) released their Standards for Technological and Engineering Literacy in STEM education. In combining engineering and technology to describe technological and engineering literacy, ITEEA (2020) takes the position that technology and engineering are inherently interrelated because engineering is the process by which technology is developed and utilized to arrive at various solutions. Similar to the NGSS (NGSS Lead States, 2013), the Standards for Technological and Engineering Literacy (STEL) also comprise three main components: “core disciplinary standards, technology and engineering practices, and technology and engineering contexts" (ITEEA, 2020, p. 8). ITEEA (2020) describes technological and engineering literacy as having an "emphasis on process and action, including designing and making" (p. 1), and enumerates a number of standards to further define the elements comprising technological and engineering literacy. Specifically, the ITEEA defines "technological and engineering literacy [as] the ability to understand, use, create, and assess the human-designed environment that is the product of technology and engineering activity" (p. 3). This differs from the previous definition (ITEA, 1996) through the new emphasis on the integration of technology and engineering, as well as a more explicit articulation of the relationship between technology (and engineering) and humanity. STEL is often exemplified through engineering design challenges and competitions (ITEEA, 2019, 2020), such as tasking students with building the tallest tower then can out of simple materials like spaghetti, tape, and string that can support the weight of a regular-sized marshmallow, or participating in robotics competitions like those sponsored by VEX (https://www.vexrobotics.com/competition) and FIRST (https://www.firstinspires.org/). I will further elaborate on the concept of engineering design in the following section. Outside of the classroom, someone possessing STEL is able to "make informed decisions about technology and better contribute to its design, development, and use" (ITEEA, 2020, p. 1). Similar to the ways that the NRC (1996, 2006, 2012) has described scientific literacy, ITEEA defines the purpose of technological and engineering literacy as a set of core knowledge and skills that non-technologists and non-engineers might use to inform their decision making on issues involving technology and engineering central to their own lives. In another point of similarity, ITEEA notes the importance of technological and engineering in preparing students to enter the workforce.

Engineering

According to Jørgensen (2007), engineering as an educational discipline emerged in the 19th century, first in terms of civil engineering, followed later by mechanical, chemical, and electrical engineering. At first, engineering was seen as a predominantly practical pursuit: a means to solve practical problems, often in military and/or industrial settings (Jørgensen, 2007). However, as the discipline matured, a new school of thought saw engineering education as a vehicle for more theoretical endeavors based on physics and mathematics as opposed to technical and experimental activities (Jørgensen, 2007). Similar to how World War II accelerated certain changes in science education (DeBoer, 1991), World War II provided pressure for universities toward adopting natural science as a foundation for engineering education (Jørgensen, 2007). While Jørgensen describes a brief history of engineering education at the university level, Chandler et al. (2011), note that, despite the growing view of engineering's importance to integrated STEM education and to national competitiveness in the workforce, "there is no well-established tradition of engineering in the K-12 curriculum or as part of teacher preparation and certification processes" (Chandler et al., 2011, p. 2). Indeed, while science, technology, and mathematics in K-12 education were developing since at least the turn of the 20th century (DeBoer, 1991; de Vries, 2018), by the dawn of the 21st century, engineering in K-12 education was still woefully underdeveloped (NRC, 2009). In an attempt to provide direction on the still emerging field of engineering education within the K-12 system in the United States, the Committee on K-12 Engineering Education was established in 2006 (NRC, 2009). The committee published their first consensus report in which they outlined broad goals for K-12 engineering education, including a focus on engineering design, integration with science, technology, and mathematics, and the development of engineering habits of mind in students

(NRC, 2009). According to the committee, engineering design can be a powerful instructional strategy for providing context for science, technology, and mathematics learning, as well as providing an avenue to approach problems that can have multiple solutions (NRC, 2009). In this way, the purpose of engineering design espoused by the committee was similar to the way that engineering was viewed by the ITEA (1996), which viewed engineering as intertwined with technology and saw engineering design as a way to incorporate problem solving that supports students' technological literacy. Not only was engineering seen as supporting science, technology, and mathematics, but these educational disciplines were also seen as having the potential to reinforce engineering design projects, particularly when it comes to activities such as reverse engineering, analysis, and modeling (NRC, 2009). This is similar to the way engineering is positioned in the Next Generation Science Standards, where it is seen as more than just applied science, but instead a design framework for solving problems specific to humanity (NGSS Lead States, 2013). The engineering habits of mind referred to by the Committee on K-12 Engineering Education encompass "values, attitudes, and thinking skills associated with engineering" (NRC, 2009, p. 5). These habits of mind, in addition to the knowledge and skills of engineering, are seen as important for students to develop as inhabitants of the 21st century, and include abilities such as systems thinking, which enables them to see the bigger picture when approaching and designing solutions to problems, as well as more general attitudes such as optimism and collaboration (NRC, 2009). While the presence of specific goals for engineering education might have led to the formation of engineering content standards similar to those developed in science, technology, and mathematics, the Committee on K-12 Engineering Education (NRC, 2010) ultimately concluded that the development of separate engineering standards would be counterproductive in achieving these goals. Instead, the committee recommended that engineering be integrated into existing curricula in science, technology, and mathematics (NRC, 2010). This could be done either by embedding engineering competencies in new science, technology, and mathematics standards, or by retroactively incorporating engineering into existing standards (NRC, 2010).

Perhaps one of the most profound themes in engineering education has been engineering design as the main vehicle of engineering education espoused not only by the Committee on K-12 Engineering Education (NRC, 2009), but by organizations and scholars seeking to integrate engineering with other educational subjects (e.g., ITEEA 2019, 2020; Kelley & Knowles, 2016; NGSS Lead States, 2013; NRC, 2012). Engineering design is a problem-solving approach used by engineers (NRC, 2009). While not all engineers use, nor do all engineering problems require, a singular set of steps, there is some general agreement on how the engineering design process flows (NRC, 2009). Generally speaking, the engineering design process begins with defining the purpose of the design, or the problem to be solved, including design specifications and restraints (NRC, 2009). The next step tends to involve coming up with potential solutions and approaches to solving the problem, and then selecting one or more to build and test, often with the use of models and prototypes (NRC, 2009). The effectiveness and feasibility of these potential solutions are then assessed based on the aforementioned testing stage, and lessons learned are then incorporated into the further refinement and/or selection of an appropriate design (NRC, 2009). Engineering design is similar to Scientific Inquiry because both are processes that take systematic, critical thinking approaches to problem solving (NRC, 2009). Both make use of some similar tools, such as models and mathematics, to collect and analyze data in an effort to refine a final product (NRC, 2009). However, important distinctions between the two are that, while scientific inquiry tends to start with a specific phenomenon and end with a generalized law or theory of scientific knowledge, engineering design tends to start with a general problem and ends with a solution specific to a given context (NRC, 2009). In other words, while scientists might find that the same scientific law (e.g., Newton's Law of Inertia) underpins various related phenomena (e.g., a magician pulling a tablecloth off of a table setting, or a quarter resting on a playing card on top of a cup falling into said cup when the playing card is flicked away), for a given engineering problem (e.g., designing a robot that can take blocks on the ground and stack them on top of each other), different groups of engineers would likely design different, specific solutions depending on their given context and constraints (e.g., types of pieces, budget, time, team size, etc.).

One example of engineering design comes from Engineering is Elementary (EiE), an engineering curriculum developed by the Museum of Science in Boston for grades K-5 in order to strengthen students' technological literacy and to build the capacities of K-5 teachers in engineering and technology education (NRC, 2009). Unique features of EiE that distinguish it from other more traditional engineering curricula include the use of context in introducing engineering content, the fact that students must use an engineering design process to identify and solve problems while working in teams and integrating science and mathematics (Cunningham et al., 2020). The specific engineering design process espoused in EiE curricula is as follows:

- Ask - students identify and clarify the problem and constraints
- Imagine - students brainstorm potential solutions/approaches to the problem
- Plan - students select one of the solutions/approaches from the previous step and begin to flesh it out in more detail
- Create - students implement their selected solution/approach, creating their engineering prototype

- Improve - students collect and use data to evaluate and modify their prototype in an iterative manner (Cunningham et al., 2020).

These steps align closely with the description of engineering design given by the Committee on K-12 Engineering Education (NRC, 2009). In their study on the effectiveness of the EiE curriculum in 152 schools in North Carolina, Massachusetts, and Maryland, Cunningham et al. (2020) found that students engaged in the EiE curriculum performed better academically on science and engineering measures than students using a traditional engineering curriculum. This was attributed primarily to the linkage of science concepts with engineering design challenges present in the EiE curriculum.

Berland (2013) also describes a STEM curriculum focused on engineering, called *Engineer your World*. The program was developed in collaboration with engineers, university faculty, and secondary school educators, and revolves around students engaging with science, technology, and mathematics in the context of engineering, with learning the content and processes of engineering being a driving focus of the curriculum. The guiding principles include: (a) “contextual[ing] all student work within STEM-design challenges,” (b) “specify[ing] specific course and unit learning goals,” (c) “employ[ing] a standardized engineering design process as an instructional framework,” (d) “engag[ing] students in sensible forms of engineering practices from day one,” (e) “ensur[ing] that all science and math concepts, and technology tools employed are necessary for students’ successful completion of the STEM-design projects,” and (f) “attend[ing] to the constraints of high school and school district systems” (p. 23). This is similar to the Engineering is Elementary curriculum, and consistent with the Committee on K-12 Engineering Education’s description of engineering design (NRC, 2009). Again, similarities can be drawn between Berland’s version of the engineering design process and the inquiry teaching often supported by science educators (DeBoer, 1991) in that both focus on the processes of the discipline as a means to learn the content. It is also similar to the style of curriculum promoted in ITEEA's (2020) STEL, in that students are likewise engaged in the process of engineering, but different in that the STEL describe engineering as a process whereby students may learn more about technology, while Berland's (2013) curriculum maintains engineering as the disciplinary focus throughout.

Mathematics

Although mathematics was seen as a staple of the K-12 curriculum since before the 19th century, and has so remained today (DeBoer, 1991; Stanic & Kilpatrick, 1992), after the turn of the 19th century, the field struggled with declining enrollments in courses such as algebra and geometry in secondary schools to the point where some schools were beginning to consider and implement curricular changes such that mathematics would no longer be considered a graduation requirement (Stanic & Kilpatrick, 1992). In response to this pressure, the National Council of Teachers of Mathematics (NCTM) was formed. Similar to the other STEM disciplines, World War II had an enormous impact on educational reform in mathematics, as it became evident that there was a shortage of Americans with sufficient mathematical ability to support the nation in certain technical and military fields now seen as increasingly important (Stannic & Kilpatrick, 1992). The Sputnik launch by the Soviet Union in the following decade only served to further fuel this concern; shortly afterwards, the *New Math* movement followed (Hekimoglu & Sloan, 2005; Herrera & Owens, 2001). Similar to WWII era reforms in the other STEM disciplines, this movement focused on increasing students' technical skills and abilities, in this case by focusing exclusively on logical principles in mathematics. This led to a mathematics curriculum that was hastily thrown together (Malaty, 1988) and often disconnected from the everyday experiences of the learner as well as from the procedural knowledge of mathematics learned by the generations prior (Feynman, 1965; Malaty, 1988). Unfortunately, due in large part to a lack of appropriate professional development, this movement ended unsuccessfully, and was succeeded in the 1970s by the *Back to Basics* movement (Hekimoglu & Sloan, 2005). The *Back to Basics* movement was an effort to return to an emphasis on basic computational skills in mathematics classrooms, but despite the effort put into professional development and curriculum development, this movement was much less successful than anticipated (Hekimoglu & Sloan, 2005). The back-to-basics movement involved much rote practice of arithmetic computations, and was occasionally concerned with making mathematics more relatable to students' everyday lives (Malaty, 1988). In the 1980s, a renewed emphasis in mathematics education reform was centered around problem solving, that is using mathematical problem solving as a vehicle for learning mathematics (Hekimoglu & Sloan, 2005). As evidence of the continuing pressure to raise the bar for mathematics education, the NRC's 1989 report, *Everybody Counts*, noted the importance of mathematics and of quality mathematics for preparing students to enter the workforce, as knowledge and skills in mathematics form the foundation for success in science and technology. Here the NRC emphasized that the mathematical nature of the workforce had increased greatly from jobs of the past, and was sure to continue on this increasingly mathematical trajectory into the future. In order for the country to stay competitive, it was imperative that the quality of mathematics education increased as well (NRC, 1989). Of particular importance is the concept of mathematical literacy, sometimes called numeracy or quantitative literacy, which the NRC defines as the ability to "grasp the implications of many mathematical concepts...that permeate daily news and routine decisions" (pp. 7–8). In accomplishing this goal of furthering students functional mathematical literacy, the NRC describes necessary shifts in mathematics education, specifically the shift away from traditional pedagogical practices of lecture and rote memorization and computation exercises and toward a more constructivist approach, such as mathematical inquiry (Makar, 2012). This is in line with the NCTM description of quantitative literacy a little over a decade later as the ability “to judge claims, find fallacies, evaluate risks, and with evidence” (NCTM, 2000, p. 16). It is also similar to the ways that scientific, technological, and engineering literacy have been described in that they all involve the use of discipline-specific knowledge and skills to solve problems, answer questions, and make decisions. Due to this emphasis on problem solving and mathematical literacy, the Common Core State Standards for Mathematics (CCSSM) were developed in 2010 to focus mathematics instruction on both procedural knowledge and conceptual understanding of mathematics (CCSSI, 2010). The CCSSM included the familiar content standards for mathematical procedures such as “write and evaluate numerical expressions involving whole-number exponents” (CCSSI, 2010, 6.EE.1) that emphasized the computational aspects of mathematics similar to the *Back to Basics* movement, but also included “Standards for Mathematical Practice” (SMP; p.6) focusing on mathematical reasoning, problem solving, and modeling. For example, Mateas (2016) explains that “in lessons on identifying the constant of proportionality from various representation (content standard 7.RP.A.2.B), students can be asked to explain correspondences among tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships and how the same constant of proportionality may appear in different representations (SMP 1)” (p. 94). In this way, students are engaging in both mathematical content and mathematical thinking while working on the same mathematical task, similar to how students in a science class may engage in all three dimensions of the NGSS within the same lesson.

STEM

The term STEM was initially used by the National Science Foundation in the 1990s as a way of concisely naming the four constituent disciplines of Science, Technology, Engineering, and Mathematics (Bybee, 2013). According to Bybee (2013), STEM is a term used in many different ways by many different people. For instance, some use the term STEM to mean specifically one discipline, often Science or Mathematics. For others, it may mean both Science and Mathematics, but not in an integrated capacity, and without reference to Technology or Engineering. Still others view STEM as being mainly Science, but incorporating one or more other constituent disciplines. Other descriptions of STEM involve integrating the four disciplines in a variety of ways and to a variety of degrees, up until what Bybee describes as a *transdisciplinary* understanding of STEM, in which all four constituent disciplines are used together simultaneously. Bybee uses the terms STEM 1.0, STEM 2.0, STEM 3.0, and STEM 4.0 to indicate the number of disciplines integrated in STEM programming. Although the term STEM may be relatively new in education, the concept of integrating the different STEM disciplines is not. According to Jackson et al. (2020), efforts to integrate math and science education were underway as early as 1894, when the Committee of Ten recommended the integration of various mathematics disciplines with physics. And as can be seen from the development of each of the constituent STEM disciplines, they have been trending toward a more integrated nature. With the emergence of the NGSS, we see performance expectations for both science and engineering/technology, as well as science and engineering practices expected to be incorporated into students' learning of various different science and engineering concepts (NGSS Lead States, 2013). While the NGSS positions engineering and technology (and even mathematics) as vehicles and contexts to support science learning, the ITEEA's (2020) STEL makes use of science and mathematics concepts and contexts to support learning in technology through engineering design. In a similar fashion, it has been argued that not only can engineering drive learning in other areas of STEM, but so can science, technology, and mathematics be incorporated into engineering design for the purposes of supporting student learning in engineering (NRC 2009; NRC 2010). It should come as no surprise that learning in mathematics has also been positioned as the primary outcome of an integrated STEM pedagogical approach. For instance, Makar (2012) describes the pedagogical practice of mathematical inquiry and how it can allow for overlap with science instruction, particularly in elementary grades.

Not only that, but as each STEM discipline evolved, it eventually became useful and necessary to articulate what it means to be literate in each field. Unsurprisingly, there is much overlap in these definitions, as each has come to involve integrating and using discipline specific knowledge and skills to solve problems and make decisions in everyday life. As an example, Owens and Sadler (2020) show how a single context, genetic modification, could be approached through different but related lenses for the purposes of cultivating scientific, technological, engineering, and mathematical literacies. For science, the focus could be on genetics and inheritance, and students might grapple with using scientific knowledge and reasoning to debunk common misconceptions relating to genetically modified organisms (GMOs; Owens & Sadler, 2020). In this way, students must not only learn scientific concepts and skills, but also apply that understanding to situations they may encounter in everyday life. To develop technological literacy in this same context, Owens and Sadler suggest focusing on gene editing tools and media literacy while students investigate different ways in which GMOs are portrayed in media sources. In doing so, students are again learning skills and concepts relating to technology, and applying those skills to problem-solve in a specific, real-world context. For engineering literacy, students could engage in engineering design activities around gene splicing tools and developing mechanisms for tasks such as seed sorting and collection where they think through appropriate design constraints for selecting an optimal procedure for gene editing (Owens & Sadler, 2020). In this example, students are primarily focused on learning engineering concepts while applying them to a real-life situation. Finally, to develop mathematical literacy under the same umbrella topic, students could consider and select from among various statistical methodologies that could be used to quantify successful outcomes of different gene editing technologies (Owens & Sadler, 2020). Again, students are learning how to use and apply mathematics to concrete, real-life events. What should by this point be apparent is that a singular context can provide students opportunities to develop and apply science, technology, engineering, and mathematics concepts and skills at the same time, although one may be the primary focus.

Bybee (2010; 2013) argues that the purpose of STEM education is to develop students' STEM literacy, an application of STEM content and practices to real-life situations. According to Bybee (2013), STEM literacy consists of the following four components: (a) "knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM related-issues," (b) "understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design," (c) "awareness of how STEM disciplines shape our material, intellectual, and cultural environments, and" (d) "willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen" (p. 18). To cultivate this STEM literacy in students, Bybee argues for "providing students with experiences where they apply knowledge and skills to personally meaningful and socially relevant life situations" (p. 18). Similarly, Zollman (2012) points out that STEM literacy should be viewed as a context for driving student learning that consists of a variety of STEM knowledge, skills, and ways of knowing and doing. However, Zollman notes that while definitions of STEM literacy frequently include factors relating to society and the economy, personal needs are not generally considered (Zollman, 2012), and therefore presents a description of STEM literacy that draws on cognitive, affective, and psychomotor domains, and argues for "using STEM literacy for learning to satisfy our societal, economic, and personal needs" (p. 12). Cavalcanti (2017) proposes a similar definition of STEM literacy, stating that it involves "utility, social responsibility, intrinsic value of knowledge, philosophical value, and childhood enrichment…[as well as] scientific and technological change, role of the standards, and decision-making" (p. 46). This explicit emphasis on decision making is important in considering how students might negotiate the personally and socially relevant issues involving STEM content advocated by Bybee (2010; 2013).

Mohr-Schroeder et al. (2020) provide an in-depth summary of the research on, and importance of STEM literacy for an equitable society in the realms of decision making and civic involvement in democratic societies. They define STEM literacy as "the dynamic process and ability to apply, question, collaborate, appreciate, engage, persist, and understand the utility of STEM concepts and skills to provide solutions for STEM-related personal, societal, and global challenges that cannot be solved using a single discipline" (p. 33). This is similar to definitions of STEM literacy put forth by Bybee (2010; 2013), Zollman (2012), and Cavalcanti (2017), but incorporates both the notion that STEM learning must be interdisciplinary, and also that STEM literacy enables students to solve more complex problems than any individual scientific, technological, engineering, or mathematical literacy in isolation.

Owens and Sadler (2020) showed that STEM literacy could be developed using an overarching issue that provides social context to STEM phenomena and concepts. These types of issues have been described as socioscientific issues, or SSIs. The conceptualization of SSI in the research base has evolved over time. After it was first introduced, SSIs were regarded as isolated issues that incorporate both social and scientific elements. For example, Driver et al. (1996) used the term socioscientific issues to describe issues involving the convergence of social interest and scientific concepts, often present in policy decisions such as the (socioscientific) issues of "waste disposal, energy policy, genetic engineering, emissions of carbon dioxide, and so on" (p. 18). Other examples of SSIs include court cases prosecuting possession of marijuana and abortion legislation (Aikenhead, 1985), as both of these issues represent issues of societal relevance associated with, though not fully resolved by, science and technology. In the view of Driver et al., STEM literacy is important for making sense of SSIs and engaging in the democratic process.

As the term grew in prominence, others began to focus on certain defining features of an SSI beyond the mere incorporation of science and society should have, as well as the purpose for incorporating SSIs into the science curriculum. According to Sadler and Zeidler (2005b), SSI are "open-ended, ill-structured problems which are typically contentious and subject to multiple perspectives and solutions" (p. 72). Similarly, Barrett and Niewswandt (2010) defined SSI as complex issues that bring ethical considerations to bear on the application of scientific content and concepts. Examples of SSI include use of gene therapy to eliminate Huntington's disease and the right of individuals to pursue cloning as a reproductive option (Sadler, 2004), growing replacement organs, and to give loved ones new life (Sadler & Zeidler, 2005a). In all of these cases, the SSI represent an issue to which there is no obvious correct answer, and grappling with issues such as these involve not just an understanding of concepts in science and technology (e.g.., cell theory and reproduction), but also involve confronting ethical dilemmas testing the boundaries of what society considers acceptable. While similar to the STS movement that came before it, SSI can be seen as both extending and encapsulating STS, while adding to it the component of moral and ethical reasoning (Sadler, 2004; Sadler & Zeidler, 2005a; Zeidler et al., 2002). According to Zeidler et al. (2002) SSI are issues that not only illustrate the connection between science, technology, and society, but also involve moral and ethical components of scientific reasoning. An example could be the consideration of animal rights in the face of animal testing in health and scientific research, where students might examine the ethics of sacrificing animals in efforts to protect the human species (Zeidler et al., 2002). The animal rights issue gives social context to scientific concepts such as disease, while also introducing the issue in a way that invites moral and ethical conflict to which there is no clear and obvious resolution. Delving deeper into the distinction between SSI and STS, Zeidler et al. (2005) describe a number of problems and contradictions within STS education, such as the lack of coherence and consistency in implementation between instructional materials and actual k-12 courses and a shaky theoretical foundation, and position SSI as a theoretical framework that envelopes and extends STS, and resolves many of the problems they pointed out. In their view, SSI encompasses the following elements, all of which contribute to developing students' moral and ethical reasoning in service of promoting students' scientific literacy: using scientific evidence to support claims and decisions made with respect to the SSI; developing students STEM literacy through meaningful discussions with their peers; including a multitude of diverse perspectives relating to an SSI that represent a plurality of cultural viewpoints; and considering SSI through in-depth case-studies focusing on a particular, controversial SSI with multiple potential resolutions based on a variety of viewpoints. While the incorporation of these SSI into STEM curricula may seem questionable to some, research has shown multiple advantages and purposes of the use of SSI. For example, multiple researchers have noted that resolving SSI builds students scientific literacy, as well as helping students to develop skills in crafting and evaluating scientific arguments and the evidence supporting them, deepen their understanding of how scientific knowledge is produced, better understand the boundaries of what questions science can and cannot answer, and develop moral and ethical reasoning skills (Driver et al. 2000; Lindahl et al., 2019; Zeidler, 2014; Zeidler & Sadler, 2008).

Although many educators and researchers agree that incorporation of SSIs into STEM curricula can benefit student learning, many educators struggle with using SSIs in the classroom due to factors such as insufficient content knowledge and lack of confidence (Macalalag et al., 2020; Sanders & Rennie, 2013). To help make clear how SSIs can be used in classroom instruction, researchers began expounding on frameworks that could be used for teaching through SSIs and designing SSI-based curricula and units of study. For example, Zeidler et al. (2011) offer a framework for developing a unit of study around an SSI, consisting of eight chronological steps: (1) “Topic/subject matter introduction”, (2) “Challenging core beliefs”, (3) “Formal instruction”, (4) “Group activity”, (5) “Develop contextual questions”, (6) “Class discussion”, (7) “Teacher reiteration of content/subject matter”, and (8) “Knowledge and reasoning assessments” (pp. 287-288). In following this pedagogical framework, the teacher uses the SSI as the organizing construct for the unit of study in which students first engage with the SSI, which is used by the teacher to challenge students’ prior conceptions before teaching the related scientific subject-matter. Students then use this newly acquired subject-matter knowledge in the context of the previously presented SSI to, with the help of the teacher, collaboratively generate (unorthodox) questions and related investigations they then engage in to collect evidence they can use to answer these questions (e.g, “Why are my biceps small and my butt so big?” p. 290). In small groups, students analyze the results of their investigations to construct explanations based on their collected evidence, which they present to the class. The teacher then provides more specific questions for investigations that focus more explicitly on the scientific knowledge taught in class, but contextualized to fit the SSI (e.g., “What is a calorie and how many do I need?” p. 290). The teacher then leads the student in a debate/discussion related to the SSI before providing last-minute instruction and clarification, and ultimately implementing a summative assessment designed to assess both process and product in terms of students’ knowledge of scientific concepts and their ability to use that knowledge to construct well-supported and reasoned claims. Additionally, Presley et al. (2013) note that core aspects of instruction around SSI include units of study designed around an SSI that students find relevant and interesting, beginning the unit of study with the SSI, and the presence of some kind of capstone project that makes use of all the students have learned, both social and scientific, about the SSI through the course of the unit. Building on Zeidler and colleagues’ SSI framework, Sadler et al. (2019) incorporate the idea of centering instructional activities in which students explore scientific phenomena, engage in STEM modeling, consider social systems that interact with STEM content, compare and contrast multiple perspectives, and practice skepticism with regard to where information is coming from, all centered around a particular SSI as a focal issue. Minken et al. (2021) have further categorized these activities as comprising different social, scientific, and discursive domains of the SSI framework.

In this way, SSI has grown over the past two decades from being seen as simply an issue that is related to both scientific and social elements, to being intimately associated with the ethics and ambiguity often inherent in the intersection of science and society, to a framework for enacting instruction around the use of SSIs in the classroom.

Given that much of STEM literacy focuses on solving complex problems that cannot be completely resolved through use of a single discipline (i.e., science, technology, engineering, or mathematics), combined with the trend toward relevance and an integration of STEM content with societal context, there exists a need for pedagogical content knowledge that focuses on solving complex societal problems underscored by STEM content. The Socioscientific Issues (SSI) framework has emerged as one such promising approach for cultivating STEM literacy in the classroom (Zeidler et al., 2005). In the following section, I will further describe the SSI framework and how it can be used as a means of promoting STEM literacy.

Promoting STEM Literacy through Socioscientific Issues

The Socioscientific Issues framework (SSI) is a way for teachers to contextualize STEM content within social contexts through the use of controversial issues and ethical dilemmas (Zeidler & Keefer, 2003). According to Driver et al. (1996), Socioscientific issues are issues that “are of broad social interest and involve a science dimension” (p. 18). While SSI is similar to STS in that both focus on how science and society are linked, SSI goes a step further in strengthening this connection between science, technology, and society by using ethical dilemmas and perspective-taking to contribute to students’ moral and ethical development (Kinskey & Zeidler, 2021; Zeidler, 2005). This extra dimension in SSI can serve to make learning in STEM subjects more personal and relevant to students (Kolstø, 2001), and aid in fostering their STEM literacy skills (Johnson et al., in press; Kinskey & Zeidler, 2021). In fact, according to Zeidler and colleagues (2002, 2005), SSI encompasses all that STS has to offer, and then some, while re-focusing STS in terms of pedagogical strategies and classroom practice.

Sadler et al. (2019) present a framework for teaching using SSIs in which teachers identify an SSI, and prompt students to "explore underlying scientific phenomena," "engage in scientific modeling," "consider issue system dynamics," "employ media & information literacy strategies," "compare & contrast multiple perspectives," and "elucidate [their] own position/solution" to the SSI (p. 17). In this framing, SSI can be "local and global controversies related to almost any science or mathematics topics" that are relevant both to students' lived experiences and to the school or district curriculum (Zeidler & Kahn, 2014, p. 31). For example, teachers developing and implementing SSI lessons engaged their students in issues relating to GMOs in school lunches, community gardens, and tap vs. bottled water (Minken et al., 2021). In resolving these SSIs, students must consider social impacts of the STEM content they are learning, thus guiding students to use STEM knowledge and skills to make decisions relating to their everyday lives (Johnson et al., in press; Owens & Sadler, 2020), which is foundational to STEM Literacy (Bybee 2010, 2013; Cavalcanti, 2017; Mohr-Schroeder et al., 2020; Zollman, 2012).

Amidst rising concerns for relevant and equitable curricula, SSI can be seen as an avenue to provide STEM teaching through a more justice-centered approach (Dos Santos, 2009; Morales-Doyle, 2017). However, engaging in social justice pedagogies in general is not always easy for teachers, and often underexplored for STEM teachers in particular (Kokka, 2018). For instance, teachers often struggle with implementing SSI due to issues with time constraints, confidence, and support (Fadzil, 2017; Saunders & Rennie, 2013). In the following section, I will elaborate on the specific knowledge for teaching STEM and SSI, both in general and toward aims of justice, using the concept of pedagogical content knowledge first promulgated by Lee Shulman (1986).

Teachers' Pedagogical Content Knowledge within STEM Education

Shulman (1986) described teacher knowledge as consisting of three categories: subject matter content, curricular, and pedagogical content knowledge. Subject matter content knowledge refers to a teachers' knowledge of the content covered in the course(s) that they teach. For example, a biology teacher should possess an understanding of the overall landscape of the field of biology, including the competing ways it may be organized and why, as well as particular skills such as using a microscope to identify and distinguish between things such as unicellular organisms, parts of a cell, types of cells, different biological tissues, etc. Curricular knowledge is the knowledge that teachers have about curricular resources, standards, and guidelines related to the course(s) they teach. Teachers display a high degree of curricular knowledge by their knowledge of various curricular programs and resources available to teach their subject, as well as an understanding of what their students are learning both in other subjects in the same grade level, and within the same subject at different grade levels, so that they can make those connections for their students in their teaching. While these two types of knowledge are both important, perhaps even essential, for good teaching, pedagogical content knowledge is another very important area of knowledge for teachers to have. In this schema, pedagogical content knowledge (PCK) "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*" (p. 9). In other words, PCK encompasses not just knowledge of a particular content area, but also knowledge of how to teach that particular content area. Grossman (1990) saw PCK as consisting of teachers' knowledge and beliefs about instructional strategies, curriculum, students' understanding of the content, and the purpose or goal of teaching. Shulman (1987) described PCK as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8). Similarly, Gess-Newsome (1999) identifies PCK as a special and separate identity, calling PCK "the transformation of subject matter, pedagogical, and contextual knowledge into a unique form – the *only* form of knowledge that impacts teaching practice" (p. 23). Gess-Newsome (1999) uses a transformative model to explain that, while teachers' PCK is based on their subject matter knowledge, pedagogical knowledge, and contextual knowledge, PCK is more than just the sum of its parts. In fact, PCK is not merely the overlap of these three knowledge domains, but rather a new domain of knowledge that results from the synthesis of the other three domains. For example, when responding to student work samples of scientific argumentation, teachers were able to assess students' understanding based on students' use of claims, evidence, reasoning, conceptual understanding, personal connections, and literary conventions to different degrees (McNeill & Knight, 2013). This type of knowledge exemplifies PCK because it shows that teachers have knowledge that goes beyond pedagogical knowledge (e.g., how to assess and provide feedback on student work) and content knowledge (e.g., the subject matter that students should be including in their arguments) and instead results in a blend and synthesis of these types of knowledge to enable them to give feedback that targets not just student's conceptual understanding of the subject matter, but also the degree to which their practice of argumentation is reflective of actual scientific argumentation and how to provide feedback to move them closer to that goal.

PCK has gained importance as an important conceptual model in the field of education (Gess-Newsome, 1999) because, according to Shulman (1986), PCK explains the degree to which teachers know and understand a) how to make content understandable, b) the preconceptions different learners are likely bring to the table that will make it easier or more difficult to learn the content, c) effective instructional strategies, and d) knowledge of current educational research. Over time, however, PCK has in some respects become a catch-all term for a variety of different ideas about teacher knowledge (Gunstone, 2015). In short, PCK has come to mean many different things to many different people. As a research paradigm, PCK has been used primarily in science and mathematics education, with the model of PCK described by Magnusson et al. (1999) as the most prolific (Gess-Newsome, 2015; Wilson et al., 2018). This model delineates four different categories of knowledge (i.e., knowledge of curriculum, students, instructional strategies, and assessment) that make up teachers' PCK, which shape and are shaped by teachers' orientations to teaching their specific content (Magnusson et al., 1999). Predominant in Magnusson et al.'s framework is the notion of orientations to teaching that different teachers may possess. These orientations represent different perspectives, goals, and visions that lead a teacher to have a particular understanding of the purpose of teaching (e.g., activity-driven, inquiry, didactic, etc.). This model of PCK has been influential in the ways that other researchers view and understand PCK (Gess-Newsome, 2015), including research that goes beyond science teaching (e.g., Hynes, 2012), for which it was originally developed (Magnusson et al., 1999). For example, Schneider (2015) views science teachers' PCK as consisting of orientations to teaching; the curriculum as a whole; teaching frameworks, or approaches; students' thinking about different science topics; and instructional strategies. This is similar to the PCK described by Magnusson et al. (1999) in that it incorporates all the same components, although Schneider groups teachers' knowledge and use of assessments in the same category as instructional strategies, and insteads separates teaching frameworks from their orientations toward teaching, which Magnusson and colleagues had grouped together.

However, no model is without its limitations. According to Friedrichsen and Berry (2015), the model of PCK described by Magnusson et al. (1999) can lead to an unhelpful understanding of PCK because it encourages thinking about different components of PCK in an isolated nature, and because it does not take into account the ways teachers actually put their PCK into practice and how this might change over time. While Magnusson et al. (1999) argued that "[PCK] is a teacher's understanding of how to help students understand specific subject matter" (p. 96), this seemingly simple definition led to increasing confusion and disagreement over time (Gess-Newsome, 2015). As the research on PCK evolved, it was realized that, not only was PCK content-specific, it was also context-specific (Shulman, 2015). For example, teachers utilize different PCK when teaching the same content with the same class of the same students depending on contextual factors such as time of day, time of year, proximity to holidays, field trips, and/or special events, personalities of students, length of class period, etc. Some shortcomings of the initial conception of PCK include a lack of attention to moral, ethical, and motivational factors inherent to teaching, a preoccupation with teachers' knowledge without regard to the ways that knowledge is acted upon, both in terms of process and product, and the failure to consider the social and cultural contexts of teaching (Shulman, 2015). This divergence of PCK research eventually led to a PCK Summit, in which educational researchers gathered in an effort to reach consensus on exactly what PCK meant (Gess-Newsome, 2015). While consensus was not expected to be universal (Shulman, 2015), some important distinctions were made in further clarifying the meaning of PCK. For example, Gess-Newsome (2015), in her presentation of a consensus model of PCK from the PCK Summit, distinguishes between personal PCK and what she describes as topic-specific professional knowledge (TSPK), or what others have called canonical PCK (e.g., Smith et al., 2018). This distinction clarifies two different types of knowledge related to PCK: knowledge that is personal and specific to an individual teacher (i.e., personal PCK) and knowledge that is more general and widely accepted, held by the profession (i.e., TSPK; Gess-Newsome, 2015). A second point of clarification relates to the grain size of PCK, that it is not so much content-specific as it is topic-specific (Gess-Newsome, 2015). In other words, there is not a PCK for chemistry, biology, and physics, but rather a PCK for ionic bonds, Punnett squares, and conservation of momentum, as each topic, even within a single course, may require a different set of teacher knowledge (Gess-Newsome, 2015; Sloan et al., 2018). An additional point of clarification relates to the distinction between what teachers *know* versus what teachers *do* in the classroom, leading to a distinction between teachers' personal PCK and their personal pedagogical content knowledge and skills (PCK&S; Gess-Newsome, 2015). Gess-Newsome (2015) defines these two constructs as follows:

> Personal PCK is the *knowledge* of, *reasoning* behind, and *planning* for teaching a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes.* (p. 36).
>
> Personal PCK&S is the *act of teaching* a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes.* (p. 36).

Note that both PCK and PCK&S are specific to a given topic, and imply an understanding of instructional strategies, objectives, students, and assessment strategies. The main distinction is whether this is something a teacher knows (PCK) or something a teacher does (PCK&S). While PCK can be inferred from teachers' planning and PCK&S can be inferred from observing teachers' instruction, both of these constructs can be somewhat implicit, but can be made explicit through teachers' reflection on planning and practice, respectively (Gess-Newsome, 2015; Smith et al., 2018).

This makes PCK a useful framework for examining teachers' knowledge and how it develops. In the following sections, I will explore how PCK has been conceptualized and utilized in research in Science, Technology, Engineering, Mathematics, and integrated STEM education, and then argue for dimensions and types of PCK necessary for teaching integrated STEM through a social justice lens.

PCK in Science

Magnusson and colleagues (1999) argue that PCK is a critical component of both effective science teaching and effective development of science teachers. There is some consensus in the literature base that teachers' PCK includes their knowledge of both instructional strategies and of student thinking (Smith et al., 2018), and how teachers use this knowledge to navigate their instruction. For instance, Watkins and Manz (2022) describe the ways in which teachers navigate uncertainty regarding scientific demonstrations to successfully facilitate classroom discussions. Their analysis unearths the myriad of decisions teachers must consider in what may otherwise appear to be a straightforward learning activity, such as decisions relating to when and how to engage with students' uncertainty about phenomena, how to generalize the uncertainty of one student to create a question or problem for the larger group, deciding what freedoms and constraints to provide for students engaged in making sense of scientific phenomena. Knight-Bardsely and McNeill (2016) found that reflecting on new instructional practices after initial implementation strengthened teacher PCK and PCK&S relating to scientific argumentation. This was seen as teacher belief and practice shifted from valuing explanation-based student arguments toward a more sophisticated emphasis on the role of evidence and reasoning in students' arguments. At the same time, development of teachers' PCK in science is not always straightforward. As an example, Barendsen and Henze (2019) found that a veteran chemistry teacher developed general, albeit minimal, PCK regarding the integration of context into science instruction, as opposed to PCK specific to the topic of the lesson under consideration. Further, the teacher's observed PCK&S did not seem to mirror the teacher's PCK: although he expressed general orientations, attitudes, strategies, and knowledge of students, Barendsen and Henze observed little evidence of these orientations, attitudes, strategies, and knowledge of students in observations of the teacher's classroom practice. For example, while the teacher articulated a PCK of inquiry-oriented, student-centered instruction, in practice, the teacher's PCK&S consisted mainly of lecture-based instruction, with more structured, teacher-driven activities for students. This may suggest the importance of developing topic-specific PCK prior to implementing new, reform-oriented classroom practices. On the other hand, some teachers chose not to try new instructional strategies presented during professional development workshops, and instead reused and renamed existing activities; in these instances, teacher PCK did not change (Knight-Bardsley & McNeill, 2016).

PCK in Technology (TPCK)

PCK within technology education has been explored in terms of both "high-tech" and "low-tech" technology education (Mishra & Koehler, 2006). According to Bender et al. (2015), computer science teachers with well developed PCK are able to adapt their teaching in such a way that they are meeting the standards set by the state, the policies set by their school and school district, and the needs of their specific students so that their students are able to learn and think creatively in the context of computer science. Similarly, Mishra and Koehler (2006) note that PCK in Technology tends to encompass teachers' understanding of ways in which technology can be used to enhance their instructional practices, such as the use of software to help with common instructional needs such as grading, attendance, facilitating student discussions, and providing feedback on student work. Qian and Lehman (2019) point out that, in order for teacher feedback to be useful, it needs to make the differences between what was expected from the student and what the student actually did visible to both the teacher and student. Additionally, teachers with advanced degrees and background knowledge in computer science were better able to accurately comprehend student's misconceptions in the classroom (Qian et al., 2020), suggesting that academic courses and professional development may enhance teachers PCK. For example, teachers have described student misconceptions in computer science that include the idea that the name of a variable is what gives it meaning, as opposed to the value to which it is assigned (Qian & Lehman, 2019).

PCK in Engineering

According to Hynes (2012), PCK for engineering teaching is often adapted from PCK of science or mathematics in new teachers. In attempting to implement engineering design in their classrooms, some teachers reported challenges with engaging students who make mistakes during the engineering design process, as the students often withdraw and struggle to take risks (Porter et al., 2019). This challenge was tied to others such as lack of resources and guidance for planning lessons around engineering design: teachers struggled to incorporate multiple components of engineering design when developing their plans (Porter et al., 2019). Some researchers have noted that making their teaching more relevant to their student population has helped to overcome many of these challenges (e.g., Sun & Strobel, 2014; Hynes, 2012). For example, elementary teachers saw that students had difficulties conceptualizing engineering as a profession, discipline, and practice, and struggled to differentiate between making things and designing things (Sun & Strobel, 2014), which are important steps in engineering design (NRC, 2009). To help students better make sense of engineering, the teachers brought in guest speakers and had students ask their families about the topic of engineering design (Sun & Strobel, 2014). Similarly, Hynes found that middle-school teachers who showed high levels of understanding of two specific steps in the EDP: “step 5: construct a prototype and step 8: redesign” (p. 357) evidenced their PCK of engineering by using examples and analogies in their teaching that were relatable and easily understood by their students.

PCK in Mathematics

PCK has become an accepted and useful construct for describing teacher knowledge of mathematics (Thompson, 2018). For example, PCK has been used to create and recreate graduate level mathematics courses for teachers that include analysis of student misconceptions, mathematical problem solving, and geometric proofs (Thompson, 2018). Within mathematics, PCK can also be thought of as topic-specific, as seen by mathematics teachers’ uneven depth of understanding across various mathematical topics (DePiper & Driscoll, 2018), such as proportional reasoning, arithmetic, and solving systems of linear equations. Similarly, Turnuklu and Yesildere (2007) found that pre-service teachers in Turkey often struggled to appropriately identify and respond to students misconceptions based on student work due to the teachers underdeveloped content knowledge of various mathematical topics, such as fractions and negative numbers. Ball et al. (2008) note the importance of “knowing different instructionally viable models for place value, knowing what each can reveal about the subtraction algorithm, and knowing how to deploy them effectively” (Ball et al. 2008, p. 402) in elementary mathematics teaching in order to help students overcome common stumbling points and misconceptions. In fact, student misconceptions are often the cause of systematic errors in mathematics (Sarwadi & Sharill, 2014), which makes identifying these misconceptions an important part of mathematics teachers’ PCK.

PCK in Interdisciplinary STEM/SSI

Just as PCK has been explored separately in the subjects of science, technology, engineering, and mathematics, some researchers have looked at the PCK expressed by teachers engaging in integrative STEM teaching methods (e.g., Chang & Park, 2020; Guzey et al., 2020, Johnson et al., 2020; Macalalag et al., 2020; Minken et al., 2021). Similarly to PCK of these constituent STEM subjects, PCK of integrated STEM has also illuminated the ways in which teachers develop and design learning activities that blend STEM content, address student misconceptions (i.e. Minken et al., 2020), and assess student learning.

As a framework for integrated STEM education, the use of SSIs can be an attractive way of structuring STEM learning, as learning about SSI can result in teachers' desire to implement the framework. For example, Minken, Macalalag, and Richardson (2020) found that over two thirds of pre- and in-service teachers who had not previously taught lessons involving SSIs expressed an intention to do so at the conclusion of a workshop on the SSI framework. Similarly, Macalalag et al. (2020) found that teachers became more focused on real world examples of SSI, motivating students to learn STEM concepts and practices, and teaching by observing nature after participating in the STEM teaching methods course. SSI is also beneficial in terms of developing students' argumentation and reasoning skills, which are important in cultivating students' STEM literacy. For example, teachers had more success with developing scientific arguments when the scientific concepts were grounded in more familiar and interesting social contexts (Johnson et al., 2020). This is important, as the way that individuals navigate an SSI is often evidenced by the reasoning they express through argumentation (Sadler & Zeidler, 2005b). However, lackluster argumentation ability is not necessarily indicative of poor reasoning skills related to the SSI (Sadler & Zeidler, 2005b). Often, students recognize the importance of using varied sources of evidence, including scientific/mathematical evidence, in making claims, however, students struggle to actually do this when making claims relating to SSI, instead relying almost exclusively on their own personal philosophies and beliefs, irrespective of scientific evidence (Zeidler et al., 2005). In this respect, class discussion can be important in deepening understanding of, and resolving, SSIs (Driver et al., 2000) because it “challenges the core beliefs of students” (Zeidler et al., 2002, p. 344).

Just as there are many different ways of teaching SSI, teachers also have different reasons for teaching SSI (Lee & Chang, 2010; Zeidler, 2014). For example, some teachers view the incorporation of social contexts in STEM teaching as a way of increasing student engagement, while others place importance on the embedding of science within social systems and of social systems within science (Lee & Chang, 2010). Chang and Park (2020) used a theory of pedagogical content knowledge specific to teaching socioscientific issues, which they call SSI-PCK to analyze changes in teachers’ PCK throughout a teacher education course. SSI-PCK is composed of six different components: a) orientation for teaching SSIs, b) knowledge of instructional strategies for teaching SSIs, c) knowledge of assessment of SSIs, d) knowledge of curriculum, e) knowledge of learning context, f) knowledge of students’ SSI learning. In this framework, the first component, orientation for teaching SSI, serves as a foundational and guiding component for the other five, in that each of the subsequent five SSI-PCK components builds on teachers’ orientation for teaching SSIs. They found that “discussion [activities] can be effective in...promoting orientations toward SSIs” (p. 425), that hands-on engineering activities could “promote teacher knowledge of instructional strategies,” and that lesson planning was important for developing teachers PCK of instructional strategies for teaching SSI.

Other researchers have also explored teachers' notion and pedagogy of STEM education. For instance, Gale et al. (2019) investigated the ways in which students were able to engage in engineering Disciplinary Core Ideas (DCIs) in an 8th grade science classroom through the use of the SLIDER curriculum. In their study, Gale et al. found that "students required a minimum of three design iterations to address the engineering DCIs; however, some teachers found this level of engagement difficult to justify" (p. 28). It may therefore be helpful to note that when conducting project-based learning activities, teachers must be intentional in using questions and giving constructive feedback to drive student learning of the scientific concepts underlying a project (Guzey et al., 2020).

Social Justice STEM Pedagogy

Just as there has been increasing pressure for societal relevance in STEM over the past century (DeBoer, 1991), there has likewise been a growing movement, albeit more recent, to infuse social justice pedagogies into STEM subjects. Although a thorough unpacking of the origins and theoretical perspectives associated with the term social justice is beyond the scope of this dissertation, it is worth noting that, while social justice is ill-defined in the literature (Boyles et al., 2009; Gewirtz, 1998; North, 2006), most conceptions of social justice involve confronting and dismantling systems of oppression, and reject the notion that teaching, even in STEM, is apolitical. For example, Young (1990) defines social justice as "the elimination of institutionalized domination and oppression" (p. 15), and Dos Santos (2009) points out that scientific literacy has an inherent political purpose, which can either be in the maintenance of the status quo which perpetuates oppression, or can be in the service of liberation. Dos Santos argues that science education "should be widened to include sociopolitical discussions around the scientific concepts taught" (p. 378). In practice, this has proven difficult (Dimick, 2012): All too often, STEM initiatives focus on the technical skills and content knowledge associated with STEM disciplines, but fail to relate said knowledge and skills to students' lived experiences, nor do they account for the need for developing the practical STEM literacy of students who will not go on to pursue STEM careers (Zeidler, 2016). This may point to a need for developing teachers PCK of STEM that involves these ideas of social justice, often implemented through the use of SSI. While there is some divergence in the conceptualization of PCK, Gess-Newsome (2015) positions PCK as "the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (p. 36). Although this understanding of PCK stems from the notion that PCK is both personal and topic specific, there is much research to support the idea that there are areas of teachers' PCK that can be thought of as institutional knowledge common to the profession (Ball et al., 2008; Hynes, 2012; Magnusson et al., 1999; Mishra & Koehler, 2006), sometimes referred to as canonical PCK (Smith et al., 2018). In the remainder of this section, I will argue for, and describe, dimensions of canonical PCK necessary to build students' STEM literacy skills through a social justice lens, focusing on the following five dimensions: *Authenticity*, *STEM content*, *sociocultural context*, *problematization*, *agency & action*, as shown in Figure 1 at the end of this section.

Authenticity/Authentic Activity

The topic in SJSP is a given socioscientific issue (SSI)/social justice science [STEM] issue (SJSI), often framed as a question:

- Is a sugar tax a good idea?
- Will a plastic bag ban help the people who live in Philadelphia?
- Should speed limits in Philadelphia be reduced?

- Should we serve GMOs in school lunches?

While any of the above SSI/SJSI questions could potentially serve as an effective means of organizing instruction, what makes all the difference is how authentic this SSI is to the particular learners in the teacher's classroom. Learning experiences can be considered authentic when they involve issues that are both real-world and that are relevant to the learners (NRC, 1999; Mims, 2003). For example, an SSI centering around the question of whether or not a plastic bag ban will help the people who live in Philadelphia would be considered real-world because Philadelphia has recently implemented a plastic bag ban (Pulcinella, 2022), but would only be considered authentic if the learners involved find this issue relevant to them. Therefore, it follows that the teacher must have the PCK to understand, appreciate, and, to some degree, anticipate what issues might be relevant to the particular students they teach (Gess-Newsome, 2015; Lee, 2016; Magnusson et al., 1999).

In SJSP, this authenticity should extend to and frame all other domains within SJSP. Within the SSI/SJSI used to organize an SJSP unit of study, there must be emphasis placed on both the *sociocultural context* and the *STEM content*. For instance, an SJSP unit of study surrounding the SSI: Is a sugar tax a good idea?, teachers could emphasize the sociocultural context surrounding sugar in students' communities: how it is used, how often it is used, why it is used, and who it is used by, and the impacts of taxing sugar in this context. By connecting the SSI to the students' lives and to their communities, the teacher is building on the authenticity inherent to the chosen SSI. Additionally, teachers could focus on the STEM content underlying a sugar tax, which might be nutrition, biological macromolecules, fitness, unhealthy side-effects, percentages, graphs, or functions, depending on the course the teacher is teaching. Again, the STEM content being explored is embedded within the authentic SSI chosen for the unit.

Furthermore, it is the authenticity of the organizing SSI that allows students to, upon reflection with each other and with guidance from the teacher, engage in problematization by revealing issues of injustice and oppression, and around which teachers can design learning activities that empower students to not merely expose such injustice and oppression, but also to address them, which supports the SJSP domain of *agency & action*. For example, continuing with the sugar tax example, teachers might guide student discussions around how different people and groups of people might be impacted by a sugar tax: who consumes the most sugar? Who is most impacted by increased prices due to such a tax? Who is afforded the most access to healthier alternatives? Is this fair? What can/should be done about this? What role can the students play in resolving this SSI? In order to do this, the teacher must prepare and plan sufficiently to have some tentative answers to these questions, and any other questions that might be relevant given the student's contexts, along with data for students to examine that could help to reveal such issues of injustice. The teacher should also be prepared to assist students with developing a realistic plan of action that students could enact in order to address issues of injustice and oppression inherent to the SSI. However, none of this is possible, much less engaging, for learners unless the organizing SSI chosen by the teacher is authentic to the learners (Mims, 2003; NRC, 1999).

STEM Content

Cochran-Smith et al. (2009) note that, despite the recurrent critique that educators engaged in social justice pursuits ignore or devalue the importance of academics in education, social justice educators do, in fact, strive to improve student learning. For instance, AP Chemistry students engaged in a justice-centered soil project not only engaged with issues of justice, but also met content standards and displayed technical proficiency with traditional chemistry skills such as predicting the products of chemical reactions (Morales-Doyle, 2017).

Moreover, teaching for social justice is incomplete without a focus on students successfully learning academic content (Ladson-Billings, 1995a; Morales-Doyle, 2015, 2017). For example, Ladson-Billings (2009) found that many elementary and middle school teachers saw taking a social justice orientation toward subjects like mathematics as an important way of engaging and motivating their students to learn the academic content. Indeed, academic success is an important component in many theories of social justice education (Dimick, 2012; Ladson-Billings 1995a, 1995b; Rodriguez, 1998). Ladson-Billings (1995a), in her framework of culturally relevant pedagogy (CRP), positions academic success as a choice students must want to make. Therefore, teachers practicing CRP see it as their duty to make the idea of academic excellence appealing to their students, such that they will want to, and choose to, engage academically. Dimick (2012) also notes the need for academic success in a social justice-oriented classroom, urging educators "that students be taught competitive academic knowledge and skills so they can succeed in today's educational, social, and economic structures, while also being taught to think critically about the ways these structures affect their lives" (p. 96). Furthermore, engaging students in STEM content is important for building their STEM literacy. Research suggests that powerful ways of doing so involve facilitating student exploration of underlying scientific phenomena and/or concepts in mathematics associated with an SSI (Sadler et al., 2019). Not only that, but students should also be engaged in the process of STEM modeling, by which they develop, critique, evaluate, and revise explanatory models of phenomena, and use these models to make predictions to be tested through future investigations (Macalalag, 2012). In SJSP, teachers need additional strategies to facilitate student learning of *STEM content* within the sociocultural context provided by the SSI. In this way, teachers could engage students in phenomena-based learning, where students are first presented with observable phenomena, such as a video of a sudden and short lived hailstorm, a demonstration of ice cubes melting at different rates on different surfaces, in order to drive student questioning and inquiry into the STEM content underlying said phenomena (NRC, 2006; Sadler et al., 2019). Additionally, teachers should facilitate student inquiry into the academic content associated with the SSI through STEM modeling, where students investigate phenomena related to the SSI in order to develop, revise, critique, and evaluate STEM models that attempt to explain said phenomena (Macalalag, 2012).

Rodriguez (1998) suggests that educators utilize authentic activities to teach their content. Activities can be considered authentic when they are physically and intellectually engaging, and designed in such a way that learners must "reflect on how the subject under study is socioculturally relevant and tied to everyday life" (Rodriguez, 1998, p. 600). This is similar to the way teachers engaging in CRP used social and cultural context to make learning activities more engaging for their students (Ladson-Billings, 2009). STEM teachers can use the SSI framework to incorporate this needed context (Dos Santos, 2009), although this can be challenging. Morales-Doyle (2015) notes that teachers often need to strengthen, and in some cases re-learn, their content knowledge in order to use SSI effectively. Because the incorporation of social and cultural context is so important for students' academic success, sociocultural context forms the next dimension of a social justice STEM pedagogy (SJSP) framework.

Sociocultural Context

Another important aspect of social justice pedagogy in STEM teaching is the contextualization of STEM content within relevant sociocultural issues (Dodo Seriki, 2018; Gutstein, 2003; Zeidler, 2016). For example, Gutstein (2006) developed 17 social justice mathematics projects that all featured this integration of sociocultural context with mathematics concepts, such as the exploration of possibilities for biases in traffic stops through probability, proportions, and percentages. Similarly, Ladson-Billings (1995a) describes the need for cultural competence in teaching, which is a way of maintaining, valuing, and affirming students' home cultures in order to provide a foundation on which to situate their new learning. Teachers can build and maintain students' cultural competence by connecting STEM content with students' lived experiences. As an example, four pre-service teachers connected the concept of pollution with students' home cultures by prompting them to make connections between the content they learned in class and the ways that this pollution might impact the lives of those in their household and community (Mensah, 2011). In order to set the stage for learning through a relevant *sociocultural context*, teachers need instructional strategies for facilitate student exploration of an organizing SSI, associated dynamic social systems (e.g., politics, religion), and perspectives of multiple stakeholders impacted by the organizing SSI (Minken et al., 2021). Teachers can have students explore the organizing SSI by engaging with resources such as videos and readings, and discussions and writing assignments based on these resources. Teachers could also have students engage in argument line activities, where students can give an initial reaction to an SSI and share their viewpoint with the larger group (Kahn, 2019).

Another way of welcoming sociocultural contexts associated with an SSI into the classroom is through dialogic conversations (Freire, 1970/2000; Rodriguez, 1998), which can provide opportunities for students to bring their own personal, social, and cultural understandings to the table in discussion of STEM content (Morales-Doyle, 2020). For example, in teaching about prescription drugs, a teacher began the unit with a dialogic discussion in which "students had the opportunity to think about the ways members of different social groups are positioned vis-à-vis the social impact of scientific knowledge" (Morales-Doyle, 2020, p. 654). In engaging in this type of discussion, it is worth reiterating the necessity in SJSP of including and examining multiple, diverse perspectives with respect to the organizing, authentic SSI. In order to successfully engage a class in dialogic conversations and discussions, it is important that teachers have, as a prerequisite, created a classroom environment in which students can feel safe, valued, and supported, free from discrimination and oppression (Dimick, 2012). Use of dialogic conversations in the classroom can support students' academic success by grounding the STEM content in a sociocultural context relevant to students' lives, thereby heightening their engagement. And, while the incorporation of sociocultural context is an important aspect of teaching STEM for social justice, it is not enough to merely make students aware of social contexts: it is also important for teachers to create opportunities for students to critique STEM in society, to not just illuminate but to make problematic issues of injustice as they intersect with STEM content. In the following section, I elaborate on this idea of *problematization* in SJSP.

Problematization

Many theories of social justice in STEM education emphasize the importance of critiquing issues of injustice as they arise in STEM classrooms (Dos Santos, 2009; Dimck, 2012; Freire, 1970/2000; Gutstein, 2003; Ladson-Billings, 1995a, 1995b; Morales-Doyle, 2017, 2020; Rodriguez, 1998). While different scholars have given this practice different names, the term problematization is used here, in reference to what Freire (1970/2000) describes as problem-posing education. Problem-posing education is the practice of re-presenting to students various sociocultural contexts, practices, and norms that arise from dialogic conversations in ways that encourage students to examine political, oppressive, and exploitative conditions such that students become motivated to investigate and resolve these issues (Freire, 1970/2000; Morales-Doyle, 2020). In STEM education, SSI can be used as the focal point for such problematization, as they center STEM content within a sociocultural context, when investigation of their context reveals issues of injustice, oppression, and exploitation (Dos Santos, 2009; Morales-Doyle, 2017). In examining an SSI, it is important to cultivate students' reflective scientific skepticism through evaluating and critiquing different sources of information, both STEM and social in nature, by having students analyze these sources of information for methodological validity, bias in viewpoints, and consideration of those advantaged and disadvantaged by the position being affirmed regarding an authentic, organizing SSI (Minken et al., 2021; Sadler et al., 2019). Esposito and Swain (2009) have noted that, when teaching in ways that are socioculturally relevant, social justice issues tend to emerge organically, thus the use of SSI as focal points in teaching is well suited to teaching STEM for social justice. SSI that fit this category are sometimes called social justice science issues (SJSI; Morales-Doyle, 2017).

This use of SSI through problematization can lead students to more critically reflect on their world (Dos Santos, 2009; Morales-Doyle, 2017), and to develop the ability to "critique the cultural norms, values, mores, and institutions that produce and maintain social inequities," which Ladson-Billings (1995a, p. 162) refers to as critical consciousness. Others have pointed to the importance of developing this critical consciousness in STEM through the contextualization of STEM within sociocultural issues (Dimick, 2012; Gutstein, 2003). For example, Dimick (2012) describes the importance of teachers designing lessons that empower students to effect change in their communities, such as with a teacher who co-constructed a unit with their students that consisted of learning about chemistry and pollution of a nearby river and related river action projects generated by students. This is related to the concept of authentic activity described by Rodriguez (1998) because students are investigating a real-world phenomenon connected to their lives, and, through dialogic conversations with other students and the teacher, reflect on the sociocultural contexts in which the STEM content is situated. The activity described by Dimick incorporates and goes beyond a focus on academics and sociocultural context in that the teacher re-presented the river pollution as a problem to be solved (as opposed to an immutable fact), and supported the students in developing and implementing related solutions. However, the teacher faced challenges with engagement and respectful critique of others by students, underscoring the importance of establishing a classroom environment in which all learners feel valued before beginning a unit of study involving SSIs or SJSIs.

In developing students' critical consciousness through problematization, it can be helpful to consider Rodriguez's (1998) construct of reflexivity, which is the recognition of the impact of one's positionality on their values and beliefs as well as what they feel is worth learning and knowing, and "opens a window for students and teachers to examine the culture of power and explore ways to transform it for the benefit of all and not just the privileged few" (p. 601). For example, in a chemistry unit on prescription drugs, students were re-presented with the commonly expressed misconception that most scientific advancements are attributable to white male scientists of European ancestry, juxtaposed with examples of scientists of color paving the way for pharmaceutical advancements by discovering medicinal properties of a wide variety of plants (Morales-Doyle, 2020). This led the majority of students to reflect on who is and is not canonically recognized and valued STEM, and to problematize this grossly misleading social narrative in STEM. This idea of problematization is therefore an extension of the focus on academics and sociocultural context inherent in SSI, in which the teacher provides opportunities for students to reflect on the SSI with a critical eye geared toward the intersection of power, privilege, and culture. While this extension is important and necessary, it is equally important and necessary in SJSP to develop students' sense of agency and facilitate their ability to act on these SSI and thereby take steps to effect change. In the next section, I will elaborate on the final component of SJSP, *agency & action*.

Agency & Action

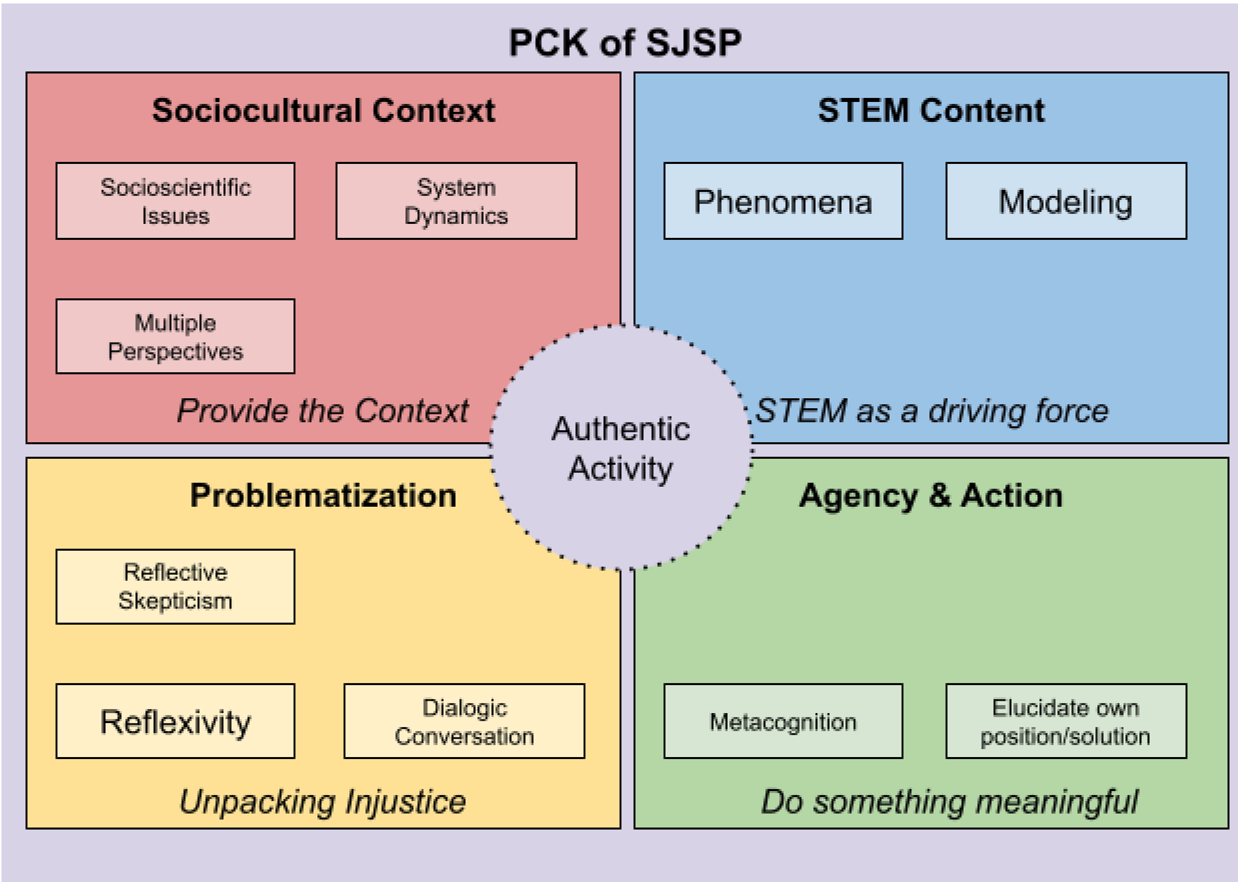
The final dimension of SJSP is agency & action. Gutstein (2003) focuses on developing students' agency as an important part of social justice mathematics pedagogy. While this is not without challenges (e.g., Garribay, 2015), the benefits involve students' ability to effect change in their communities as positive forces in the struggle for justice (Gutstein, 2007). For example, Varelas et al. (2018) found that many teaching fellows exposed to social justice orientations to science pedagogy saw themselves as conduits to developing students' agency to harness the power of science to right wrongs in their communities relating to environmental racism. Morales-Doyle (2017) also notes the importance of cultivating students' agency as they become transformative intellectuals "who can help us imagine alternate mechanisms for social change" (p. 1038).

Developing students' agency in social justice oriented STEM classrooms can also focus on students' control over their own learning. For example, Rodriguez (1998) discusses agency in terms of metacognition, in that through teaching STEM for social justice, educators should strive to encourage students to reflect on their own learning in terms of the extent to which they are learning, aspects of the lessons that enhance and act as roadblocks to their learning, and to take ownership of their learning. Supporting student's agency in their learning through metacognition can lead to action. For example, in taking ownership of their learning, students used mathematics in a community research project to uncover problems facing their community, and presented solutions and ideas at a community action night (Tan, 2009). Freire (1970/2000) notes the importance of both action and reflection, in that one without the other is meaningless. This reflection, which in Freire's view, brought about by developing one's critical consciousness through dialogue and problematization, is essential, yet insufficient in the pursuit of justice, just as action without reflection is often shortsighted and misguided. As such, teachers also need strategies to engage students in both agency and action. Engaging students in this domain requires teachers to build students' abilities to reflect on and take ownership of their own learning (Rodriguez, 1998), which can allow students to develop a plan of action, to elucidate their own position, and potentially a solution, to the issues of injustice posed by the SSI (Sadler et al., 2019). Teachers can engage students to think about root causes and manifestations of a problem revealed by the SSI through a problem tree analysis (JASS, n.d.), where teachers guide students to think about how the problem came to be, and the different ways it manifests itself in everyday life using a graphic organizer of a tree, where the contemporary problem is placed on the trunk, the roots represent the root causes, and the leaves or branches represent the manifestations. Teachers can guide students to pick one of the leaves or branches to focus on solving, and to come up with an action plan for how they could enact such a solution. In this way, teachers can support students in working towards solving issues of injustice, instead of just analyzing the problem without working towards a solution.

Therefore, in pursuit of a Social Justice STEM Pedagogy (SJSP), all of the previously discussed dimensions (i.e, authenticity, STEM content, sociocultural context, problematization) as well as the dimension of agency & action are both vital and intertwined. In SJSP, STEM content should be grounded in authentic sociocultural contexts through the use of SSI, and extended through problematization in a way that develops student agency and facilitates student action in response to the SSI. While this approach is not without its challenges (e.g., Fadzil, 2017; Saunders & Rennie, 2013), it has the potential to make STEM more relevant to more, diverse learners (Zeidler, 2016), and to develop students STEM literacy skills, along with deepening their capacity for moral and ethical reasoning (Zeidler, 2002). For example, Barton and Osborne (2002) found that engaging in a community gardening project not only helped students to make a positive difference in their community through science, but also empowered them to feel connected to and included as a member of the scientific community at large. Additionally, Kokka (2019) saw a middle school math teacher successfully engage students in math content such as fractions, coordinate planes, and positive and negative integers by embedding the content in social issues such as cyber bullying, food deserts, and single mom's living expenses. Further, investigation and discussion of these issues spurred students to take action in their own community, such as by creating signs in protest of gentrification and drafting plans to help their communities in the future.

Figure 1

Pedagogical Content Knowledge of Social Justice STEM Pedagogy



Summary

In this chapter, I have detailed the way that reforms in Science, Technology, Engineering, and Mathematics education over the past century have resulted in a somewhat steady pressure to infuse personal, social, and cultural relevance into STEM education (DeBoer, 1991; Gallagher, 1971; Hekimoglu & Sloan, 2005; ITEEA, 1996, 2020; NCTM, 2000; NRC, 1989, 2009, 2010, 2012). This emphasis on relevance eventually resulted in a push for social justice in education as a means to both engage learners and to develop students' moral and ethical reasoning abilities in hopes that this would lead to a more just world (Dos Santos, 2009; Zeidler, 2016). While this is readily accepted by many teachers as a worthy endeavor, just as many are often ill-prepared, and struggle to implement such a pedagogy (Macalalag et al., 2020; Sanders & Rennie, 2013).

With this in mind, I have explored pedagogical content knowledge (PCK) as a model for describing and analyzing the different facets of teacher knowledge involved in successfully planning for and implementing classroom instruction (Gess-Newsome, 2015; Shulman, 1986). Important in understanding PCK are both the different pools of teacher knowledge contained within PCK (e.g. Magnusson et al., 1999; Chang & Park, 2020), and a holistic understanding of the context-specific particularities of teacher knowledge (Gess-Newsome, 2015). I then explored PCK as applied to each individual STEM subject, as well as to integrated STEM education and SSI, before offering a model of PCK of Social Justice STEM Pedagogy (SJSP). This PCK of SJSP (Figure 1) organizes instruction around an authentic, organizing SSI, and is used to embed STEM content within sociocultural contexts relevant to students' lives (Minken et al., 2020; Minken et al., 2021; Sadler et al., 2019; Zeidler, 2016). Through exploration of this SSI, the teacher is able to reframe the SSI as related to issues of injustice through problematization (Dos Santos, 2009; Freire, 1970/2000; Morales-Doyle, 2017, 2020), and develop students agency and move them to act in order to help resolve the issues of injustice revealed by the SSI (Dimick, 2012; Rodriguez, 1998; Sadler et al., 2019).

Chapter 3: Methods

Introduction and Research Questions

This study used a case study design (Creswell & Poth, 2018; Yin, 2018) to explore the ways teachers in the J-STEM program develop and conceptualize their Pedagogical Content Knowledge (PCK) relating to Social Justice STEM Pedagogy (SJSP). Specifically, this study explored the ways in which teachers participating in the J-STEM program developed and refined their pedagogical content knowledge of SJSP throughout the course of the program. This study was guided by the following research questions:

1. RQ1: To what extent did teachers adapt their PCK of SJSP in the (re)development of a unit of study?
2. RQ2: To what extent did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom?
3. RQ3: To what extent were teachers' PCK of SJSP similar and different as they (re)developed a unit of study?

Research Method

This study was qualitative in nature, as the aims of this study were to explore the PCK teachers develop throughout the Justice in STEM (J-STEM; pseudonym) program that allows them to teach STEM for social justice using the SJSP framework. Qualitative research is well-suited for answering these research questions due to their exploratory and context-dependent nature, as well as the emphasis they place on teachers' perceptions and perspectives (Stake, 2010). More specifically, the case study design was selected due to the interest in the particular experience of teachers participating in the J-STEM program and the ways in which they cultivate and express their PCK as they develop and implement units of study in which they purposefully teach STEM for social justice using the SJSP Framework. Yin (2018) notes that case studies are a suitable research method for studies that focus on questions that are exploratory in nature, when the research seeks to investigate life as it happens (without researcher intervention), and when the research focuses on contemporary events occurring in the present and recent past. As such, a case study makes sense to answer these research questions, which focus on the ways in which teachers in the J-STEM program were able to develop units of study designed to teach STEM for social justice.

Yin (2018) emphasizes the importance in case study research of identifying and bounding the case under investigation. Identifying the case is done by reviewing and refining the research questions guiding the investigation, and should result in the articulation of the case as a concrete example of some real-world phenomenon (Yin, 2018). In this case, all of the research questions are focused on the PCK of SJSP for teachers participating in the J-STEM program. Therefore, the case under investigation is identified as the development of secondary teachers' PCK of SJSP in the context of the J-STEM Program. This constitutes what Creswell and Poth (2018) refer to as an intrinsic case, as it "presents an unusual or unique situation" (p. 99) where teachers of STEM subjects are engaging in structured professional learning centered around infusing social justice into STEM. While professional development around STEM is not uncommon, there are not many programs to support in-service teachers' development of PCK for SJSP, and few quality professional development programs, workshops, or other opportunities around social justice are available to most educators due to cost (Basile & Azevedo, 2022). In contrast, the J-STEM program is a grant funded program that provides teachers a stipend for their participation. Additionally, much professional development offered to in-service teachers is centered around "short-term, discrete 'events' that provide limited opportunities to support the ongoing development" of teachers' PCK (Friedrichsen & Berry, 2015, p. 215), whereas the J-STEM program offers a two-year long sustained professional learning program for in-service teachers. Bounding the case is important in deciding how to focus the case, such that there is clarity between what constitutes the case and what constitutes the context thereof. This case is bounded to the experiences and perceptions of teachers in the inaugural cohort that relate to the development of their PCK of SJSP. Other participants, staff, program activities, etc. are seen as the context within which the case resides.

This focus positions the development of teachers' PCK of SJSP within the J-STEM program as a holistic, single-case study, with the development of the individual participants' PCK of SJSP serving as embedded cases within this single case (Yin, 2018). Single-case studies differ from multi-case studies in that the single case has a single context (Yin, 2018) which, in this study, is the J-STEM program. Embedded cases represent a type of case within a case, where the embedded cases are essentially smaller units of analysis that fall within the larger case (Yin, 2018). In this study, the development of each individual participant's PCK serves as an embedded case that makes up the single-case of PCK development within the context of the J-STEM program. These embedded cases allow for teachers' PCK of SJSP to be examined in more detail through comparing and contrasting the ways in which different teachers in the J-STEM program expressed their PCK in terms of their reasoning process and the products they created (i.e., units of study and classroom artifacts). While each participant's PCK was expected to develop (or not develop) in various ways for various reasons, each of these embedded cases serves to better inform the ways in which teachers' PCK developed within the J-STEM program.

Three teachers participated in this study: Ms. Rossi, Mr. Rubin, and Ms. Moretti. Ms. Rossi is a white, female chemistry and physics teacher at a 6th-12th grade public middle/high school with 13 years of teaching experience. Mr. Rubin is a white, male 6th grade science teacher at a K-8th grade public elementary school with 14 years of teaching experience. Ms. Moretti is a white, female 6th grade science teacher at a 6th-8th grade public middle school. All of the teachers' schools are located in different neighborhoods within a large urban school district in the mid-Atlantic region of the United States and did not have previous experience incorporating sociocultural contexts and social justice themes into their STEM pedagogy prior to participating in the J-STEM program.

Context of the Study

The Justice in STEM (J-STEM) program is a four year professional development program for 6th-12th grade teachers of STEM subjects, funded by the National Science Foundation (NSF), that aims to cultivate teachers' PCK of integrating social justice into their STEM pedagogy over the course of two years. The program is located in the mid-Atlantic region of the United States near a large urban city, and provides cohorts of between 15 and 30 local teachers with two years of research-based professional development in the form of workshops, professional learning communities (PLCs), and field trips. By the end of the first year of the program, teachers are expected to be able to develop and implement a unit of study aligned to the SJSP framework, and by the end of the second year of the program, become teacher leaders in spreading and sustaining SJSP in their schools. The workshops focus on learning activities for teachers to participate in that model secondary STEM lessons using a social justice STEM pedagogy (SJSP) framework based around Socioscientific Issues (SSI; Sadler et al., 2019) and Sociotransformative Constructivism (sTc; Rodriguez, 1998). The PLCs provide teachers opportunities to learn from each other through discussion around different components of the framework and ways of implementing it in classrooms. The field trips provide opportunities for teachers to learn about local contexts, such as museums and arboretums, and how they might engage their students by connecting their unit of study to local contexts. Throughout the first year of the program, teachers work in small groups with a coach who helps them think through their unit development and implementation, and also visits their classroom to observe and provide supportive feedback as the teachers grow their practice. During the second year of the program, teachers become mentors for the incoming cohort of teachers (the program accepts one cohort of teachers during its first, second, and third years, and each cohort stays with the program for two years) as they develop their leadership skills around SJSP. Throughout the program, teachers are exposed to, and engaged in, the different domains of SJSP.

Authentic Activity

The importance of Authenticity in developing an SJSP unit of study was emphasized at multiple points throughout the J-STEM program. During one of the opening sessions, when teachers were first learning about socioscientific issues as a way to organize an SJSP unit of study, teachers were encouraged to reflect on the interests of their particular students, and the types of issues that they might find relevant. Teachers were also encouraged to brainstorm a few different potential SSIs that would fit with their content and allow their students to vote, rank, or otherwise provide feedback on which SSI they found most preferable. By taking steps to relate the SSI that organizes the unit of study to the lives and experiences of the students they teach, teachers were better positioned to develop a unit of study that was more authentic to the particular students in their classrooms.

Additionally, participants engaged in a workshop around the idea of authenticity and what that means both in STEM education, and in education in general. This workshop began with teachers responding to prompts about their beliefs regarding STEM, STEM education,

education in general, themselves, and their students. Teachers then discussed these beliefs in small groups and then as a whole group, thinking about what this means for their own teaching in their own classroom. Following this discussion, teachers were challenged to think about what it means to make learning authentic for their students, and how they could go about doing that. It was posited that, in order for learning experiences to be authentic, they must be both real-world and relevant in the view of the students. In other words, the learning must connect to both the everyday life of the learner, and to the learners interests. For SJSP, this means that the SSI teachers used to organize their SJSP unit of study must be authentic to the students: related both to learners’ lived experiences and their interests.

STEM Content

Teachers in the J-STEM program participated in workshops centered around using phenomena to engage students in STEM content related to the organizing SSI. PCK of using phenomena to engage students in the classroom involves the purpose, presentation of, and discussion surrounding the phenomena (NRC, 2012; NGSS Lead States, 2013). The purpose of incorporating phenomena into STEM lessons is to engage and excite students, as well as to challenge their thinking about how the world works (NRC, 2012). Additionally, the phenomenon should be presented without explanation, that is, the teacher should allow, and encourage, students to present their own ideas and rationales in attempting to explain how the phenomenon works, thereby facilitating discussion amongst students that promotes scientific reasoning skills based on evidence (NRC, 2012). For example, in the first J-STEM lesson of the Fall Institute, teachers were presented with an interactive map that showed locations of different car crashes in their city. Teachers discussed patterns they observed in the map, as well as possible reasons why there were more crashes in some areas than others. Following this discussion, teachers were prompted to consider how speed limits could play a role in such crashes. With all of this in mind, teachers then engaged in activities that allowed them to go deeper into the SSI of whether or not speed limits should be reduced, some of these involved engaging in STEM modeling (Macalalag, 2012) to further explore different factors, such as turning radius, and friction as it relates to road conditions, and the impact that they have on the speed of a vehicle, as well as how different materials can protect vehicle occupants during a crash. PCK of using STEM modeling in STEM classrooms involves the ways teachers guide students to use and develop models, or potential explanations, of phenomena (Macalalag, 2012; Minken et al., 2021). Specifically, teachers should guide students to develop, revise, use, and evaluate models in ways that further scientific investigations of phenomena (Macalalag, 2012; Minken et al., 2021). By engaging in the previous activity, J-STEM teachers experienced how scientific concepts such as friction, velocity, acceleration, momentum, and collisions could all be drawn out of a socioscientific issue in a way that could more meaningfully engage their learners.

Sociocultural Contexts

STEM content can be more meaningful for learners when embedded in sociocultural contexts through authentic socioscientific issues (Ewing & Sadler, 2020). In the J-STEM program, teachers engaged with a variety of SSIs, such as whether or not a newly proposed map of congressional districts was gerrymandered (Year 1, Workshop 4), the role of mask mandates in stopping the spread of infectious diseases (Fall Institute, Year 1, Lesson 3), and the aforementioned reduction of speed limits to promote safer roadways (Fall Institute, Year 1, Lesson 1). Teachers engaged with these SSIs through video clips, news articles, and discussions centered around unpacking the various systems related to the SSI that were associated both with STEM content, and sociocultural contexts. In exploring the sociocultural contexts of an SSI, teachers compared and contrasted multiple perspectives of individuals and groups of stakeholders that could be impacted by the SSI and different potential resolutions thereof. For example, in the previously discussed SSI associated with lowering of speed limits, teachers considered, discussed, and reflected on how different stakeholder groups, such as commuters, car accident victims, pedestrians, bus drivers, parents, emergency healthcare workers, truck drivers, police and traffic safety officers, and local politicians, might react to, and be impacted by, proposals to lower speed limits in their area by conducting a mock town hall meeting where different teachers were assigned the role of the various stakeholder groups. This allowed them to experience and reflect on how engaging in perspective taking might be beneficial in considering the impact of the SSI. In addition to this perspective taking, teachers considered the dynamics of different social systems and how they interact with the SSI. For instance, with regard to the same speed limit SSI, teachers researched how the SSI might impact and be impacted by systems such as the fuel industry, car manufacturers, policing, the environment, public transportation, and the local community. After researching and sharing out, teachers reflected on how this information could, or did, influence their own perspective on the SSI and what a preferable resolution to said SSI might be. By engaging in these types of activities, J-STEM teachers experienced how STEM content could be embedded in sociocultural contexts, and the impact that can have on learning.

Problematization

In supporting teachers with problematizing issues of social significance, the J-STEM program cultivated teachers PCK with respect to reflective scientific skepticism, dialogic conversation, and reflexivity. For example, on the first day of the Fall Institute, teachers were provided with five different articles from various sources relating to speed limits, car crashes, and driver safety that each espoused a particular point of view. In reconciling all of this information, teachers were directed to read with a critical eye, reflecting on biases that could affect the presentation of the information, the author disseminating the information, the purpose and/or methodology for obtaining the information presented, and those who are disadvantaged and advantaged with respect to the SSI, which in this case was whether or not speed limits should be reduced for a nearby city. In cultivating teachers' capacity for dialogic conversation, the J-STEM program involved regular critical discussions of local news articles covering topics such as construction projects, climate change, homelessness, and inflation during each PLC session. From these dialogic conversations, teachers worked together to unpack issues of injustice, STEM content, and ways of incorporating local news articles such as the one currently under discussion in their own classrooms with their own students. Additionally, teachers developed an understanding of reflexivity through activities in the J-STEM program such as creating identity collages during the 5th PLC session, in which teachers used pictures, images, and text to develop and present a collage that they felt represented who they were as a person and as a STEM teacher.

Agency & Action

In terms of the Agency & Action domain of SJSP, J-STEM teachers learned strategies to engage learners in metacognition and in elucidating their own position or solution with respect to an authentic organizing SSI. For example, in the 5th PLC session, teachers learned about strategies such as using a root cause tree graphic organizer to have students examine underlying root causes (roots), as well as the varying effects (leaves), of a given problem situated within a given SSI (tree trunk). Teachers discussed the ways that they have applied similar strategies in the past, and the potential benefits and challenges of adapting activities such as this one into their own teaching practice with their own students. Having students complete this process can cause them to think deeply about the problem under consideration, as well as how to go about solving the problem by "trimming the tree," or picking a particular effect to try and (re)solve. This allows students the opportunity to think critically about, and reflect on, their own learning, and how that learning can be used to transform their world (Rodriguez, 1998), and also to being planning steps that they can take, both inside and outside of the classroom, to not only elucidate their own position, but to enact a particular (re)solution to the SSI.

Role of the Researcher

I am in somewhat of a supervisory role related to the participants in this study, as I am visibly involved in the J-STEM program in terms of developing and implementing professional development as a workshop facilitator. I am also somewhat of a peer in that I am also a teacher in the same geographical location as many of the study participants, and I have learned from them just as they have learned from me. In my role, I want to see the participants succeed in developing strong PCK of SJSP aligned with the J-STEM framework, and I want to see the J-STEM program having a helpful and encouraging influence in that development. Additionally, because of the relationships I have built with the potential study participants, they may be more inclined to participate in this study, and to be forthcoming about their successes, possibly more so than with their challenges.

I am a white male science teacher with over a decade of teaching experience in science and STEM. Given that I, as a qualitative researcher, can be considered an instrument myself (Creswell & Poth, 2018), it is important to take a moment to unpack some ways in which my own positionality influences the way I perceive and interpret the world around me. Through my own personal experiences, I have developed a number of assumptions about how teaching typically unfolds, particularly in science classes, in the area where many of the participants teach. One assumption is that, while many teachers would like to teach STEM in ways that are more interdisciplinary, process-oriented, and culturally relevant, just as many face challenges in these areas due to constraints such as limited planning time, limited budgets for resources, administrative mandates at the school, district, and state level that dictate what is and is not focused on in the curriculum, ability to successfully manage a classroom and student behaviors, and a lack of professional development in all of these areas. I also think that the J-STEM program is unique in that it affords teachers time, professional development, coaching support, instructional resources, and a stipend, all things that can help teachers to overcome these challenges. Therefore, it is also my assumption that the J-STEM program is, in fact, helping teachers to meet these goals in various ways.

Additionally, as a white male, I benefit from white privilege (McIntosh, 1989), which can result in certain blind spots in terms of understanding how society in this country is structured in such a way that unfairly benefits me over others who are not white and/or male, and prime me to not take seriously issues of injustice raised by marginalized groups (Miriti et al., 2021). In overcoming these blind spots in research, it is important to question any supposed "neutrality" in my interactions with participants, and in my analysis and interpretation of data (Chadderton, 2012). I believe that social justice is important in making progress as a society so that everyone is able to live free of oppression, domination, and discrimination so that they can define and pursue their own goals, hopes, and dreams. I believe that the variety of different cultures that exist in our world are the embodiment of different perspectives, values, ideas, and ways of being, and that learning more about the culture we come from and the cultures around us enrich our lives and strengthen our ability to fight for social justice.

Participant Selection

For this study, I invited all 10 participants who were a part of the first cohort of the J-STEM project and have completed the J-STEM End-of-Year Interview, of which three participants consented and enrolled in this study. The J-STEM End-of-Year Interview is a data source previously collected by the J-STEM research staff with prior IRB approval that I analyzed for my dissertation research study, and is discussed in more detail in subsequent sections relating to data sources and data collection. As stated earlier, these participants were general education teachers of science in grades 6-12 who had completed two years of the J-STEM program, all of whom had over 10 years of teaching experience. This was a sample of convenience because I had access to these participants as a research assistant associated with the J-STEM project. Participants were recruited via email (see Appendix C), and were explicitly told that participation will be both voluntary and confidential, in that their participation will in no way impact their standing in the J-STEM project, their participation in my study would not be disclosed to anyone outside of my dissertation chair, and any data collected as a part of the study would be either reported in aggregate or attributed to pseudonyms. It is worth noting that, although STEM provides a relevant context for this study, the participants in this study were teachers of science, and not necessarily engaging in integrated STEM. However, these teachers are still considered "STEM Teachers," and analyzing their PCK will still provide a rich understanding of PCK of SJSP.

Methods

Data Sources and Data Collection

Measurement and analysis of teachers' PCK is often tacit and unspoken, and therefore measuring it requires tools that bring teachers' PCK to the surface in sufficient detail as to allow for thorough analysis (Smith et al., 2018). Additionally, PCK is a complex concept that cannot be fully captured through a single data source (Henze & Van Driel, 2015). As such, I used multiple data sources (Table 1) to capture different aspects of teachers' PCK related to my study. These data sources included different types of interviews and artifacts (i.e., lesson plans and sample projects from an SJSP unit of study). In the remainder of this section, I will describe each of these data sources in more detail. All data sources and related protocols are attached in Appendix A.

Interviews

As interviews are one of the most important data sources for case study research (Yin, 2018), two semi-structured interviews were conducted as a part of this study. In a semi-structured interview, the researcher prepares a list of questions ahead of time, but may deviate from the prepared questions as needed to probe deeper into new or unexpected lines of inquiry that unfold during the interview process (Galletta, 2013).

J-STEM End-of-Year Interview. The first interview (see Appendix A: Data Sources) served to capture participants' PCK of SJSP as it related to their experiences developing and implementing the SJSP unit of study they developed as a part of the J-STEM program. This interview involved case-based questions that helped to capture teachers' PCK as they reflected on plausible scenarios related to the SJSP framework that required teachers to analyze student thinking or describe potential instructional strategies (Smith & Banilower, 2015). These questions were developed and refined by the J-STEM research staff through use with participants in a preceding research project around SSI and PCK (Macalalag, Minken, & Varma, 2023). This interview was helpful in answering research questions one and two, as it helped elicit teachers'

PCK of SJSP and the extent to, and ways in, which teachers conceptualized and planned SJSP units of study that extended learning beyond the walls of the classroom.

Specifically, this interview addressed RQ1 with case-based and reflection questions that focus on the sociocultural contexts and STEM content domains of SJSP (see Appendix A). For instance, the first and second interview questions asked “1. From the beginning of the project to now, in what ways has your knowledge of social justice evolved?” and “2. From the beginning of the project to now, in what ways have your teaching practices for integrating STEM teaching with social justice goals evolved?” Question 1 relates to RQ1 because this question relates to teachers’ knowledge of social justice. Taken together with question 2, question 1 helped to elicit teachers’ PCK of SJSP because it asked about a) teachers’ knowledge of social justice, and b) teaching practices relating to STEM and social justice.

Question 4 is a scenario question that is broken down into three parts, each of which are related to an overarching scenario of mask-wearing. The first part asks teachers to consider that “the students decide that mask wearing should be optional because, if an authority figure doesn’t do it, it can’t be that important,” and asks two follow up questions. The first is “As a teacher, describe what your students are struggling to do?” This question focuses on how teachers understand student conceptions around the socioscientific issue of mask wearing, which relates teachers’ PCK of the Sociocultural Contexts domain of SJSP. Additionally, the second question asks teachers “What are you going to do to help your students evaluate multiple perspectives?” This question prompts teachers to reveal their intended instructional strategies for teaching this SSI with a focus on multiple perspectives, another aspect of teachers’ PCK within the Sociocultural Contexts domain of SJSP. As a whole, this question supports RQ1 due to its focus on teachers’ PCK of SJSP, particularly with respect to the Sociocultural Contexts domain.

The second scenario for teachers to consider is “Schools are open and the teachers, administrators are unable to stop students from hugging. Students communicating in school under 6 ft apart. Administrators cannot enforce masks wearing policy.” Again, teachers are asked to respond to two questions related to this scenario. The first is “As a teacher, can you please describe the scientific phenomenon that students do not understand?” and the second is to “Describe activities your students can investigate regarding this phenomenon.” These questions are designed to illuminate teachers’ PCK in terms of their understanding of student conceptions (first subquestion) and instructional strategies (second subquestion) as they relate to the STEM Content domain of SJSP. This focus aligns this question with RQ1, which focuses on teachers’ PCK of SJSP.

The third scenario teachers were presented with was “A group of students decided to meet in their local pizza place to hang-out. They started to eat without masks inside the restaurant, which follows the 25% capacity limit,” and prompted teachers to consider that “there are multiple articles that show dining out and its effects on economy and physical and mental health. As a teacher, how will you guide your students to scientifically evaluate and question information from different sources?” This question is focused on elucidating teachers’ PCK, specifically regarding their instructional strategies relating to engaging students in reflective scientific skepticism, an aspect of the Problematization domain of SJSP. As such, this question aligns with RQ1 because of its attention to teachers’ PCK of SJSP.

The fifth question asks teachers “How did you support students’ SSI knowledge/ability across the 3 elements of SSI (social, scientific, discursive) in your instruction and to give examples?” This question asked teachers to describe the ways in which they supported student learning with respect to their SJSP Unit of Study, and give examples of their classroom practices.

In addition, it asks teachers to reflect on their unit of study to think about what they have learned from implementing it and how they could improve it through the following subquestion: “Based on your unit, how would you modify it next time to better address these goals?” All of this relates to RQ1 because it is designed to elicit teachers’ PCK, particularly in terms of instructional strategies, as it relates to SJSP in general, by focusing on the SJSP unit of study they designed.

This interview addressed RQ2 through reflective questions that focus on how teachers prepare students to engage in learning activities that extend beyond the walls of the classroom and become with their communities. Specifically, the third interview question asked teachers “3. In what ways, if any, do your students become involved in (civic engagement) in their community? a. What have you done to prepare your students? b. Thinking about last year and this year, in what ways do you think your teaching practices change in fostering civic engagement? c. Explain why you made those pedagogical decisions.” This question focuses on how teachers prepare and guide their students to become more involved in their communities, including the reasoning behind their pedagogical decision making process, all of which is related to the Agency & Action domain of PCK of SJSP. This relates to RQ2 because it seeks to uncover how teachers are extending student learning outside the boundaries of the classroom.

The final question asks teachers, “Is there anything else that I didn’t ask, but you feel would be important to talk about?” This question is not specifically aligned to any of the research questions, but was included to reveal possible aspects of teachers PCK of SJSP that they feel are worth talking about, but which were not anticipated by the researcher. This interview was collected from teachers at the conclusion of their first year of the J-STEM program over Zoom by the J-STEM research staff with prior IRB approval.

Reflective Interview on SJSP Unit of Study. In order to elicit a more robust description of teachers' PCK, I conducted a second interview (see Appendix A: Data Sources) that asks teachers to reflect on the planning and teaching of their SJSP unit of study. Deep dives into teachers' thinking are important for eliciting their PCK, as is understanding teachers' context, being that PCK is context dependent (Gess-Newsome, 1999). Therefore, to better understand the context within which teachers make pedagogical decisions, this interview asked teachers to reflect on ways the development and implementation of their SJSP unit of study used in this study, as well as on ways they support their students in engaging in social justice actions beyond the walls of the classroom. This interview consisted of 10 questions, adapted from Grossman's (1990) retrospective interview for teaching a unit protocol, and was helpful in answering research questions one and two because it helped elicit teachers' PCK as it was expressed in their unit of study, as well as the ways in which the teachers' focused on extending learning beyond the classroom walls.

Specifically, the first question asks teachers to "Tell me about your unit on _________," in particular, "How did you introduce it?", "What were your goals for the unit?", "What kinds of things did you take into consideration in planning the unit?", "Can you tell me about some of the discussions/lessons?", "How long did the unit take?", and "How did you leverage your students' interests in choosing the SSI for this unit?" These questions are important for eliciting the teachers' understanding of the structure and purpose of their SJSP unit of study. Additionally, the probing questions ask about the ways in which the teacher considered their students in the development of their SJSP unit of study. This relates to RQ1 because a teacher's purpose and way of teaching a lesson for a particular group of students is an important part of their PCK (Gess-Newsome, 2015; Magnusson et al., 1999; Lee, 2016).

The second question asks, “Tell me about the students in the class. [probe for number of students, heterogeneity or homogeneity of class, student backgrounds and interests]”, with specific probes for “What are some of the things/issues that are high-interest to your students?”, “What activities do your students tend to find engaging?”, “What are some issues of social (in)justice that your students talk about?” This was an important question because having an understanding of the teachers’ perspective on their student population helped me to describe the ways in which teachers use their PCK to create authentic activities for their learners. This relates to RQ1 because authentic activity is a central component of PCK of SJSP.

The third question asks, “How did you draw your students’ attention to issues of injustice inherent in your SSI? [probe for instructional strategies]” This question allowed me to better understand how teachers used their PCK to engage students in problematization. This helped to answer RQ1 because of the focus on the problematization component of teachers’ PCK of SJSP.

Question four asks, “How did you facilitate student discussion around unpacking the various complexities of the SSI?” This question allowed me to focus on the ways in which teachers used their PCK to help students explore the sociocultural context related to the overarching SSI in their unit of study, and potentially how they engaged in problematization as well. This relates to RQ1 because problematization and sociocultural contexts are both components of teachers’ PCK of SJSP.

Question five asks teachers to describe “What were some of the issues of injustice that surfaced during the unit of study?” Follow up probes include, “How did you facilitate student exploration of this injustice?”, “What teaching strategies did you employ?”, “How did students’ cultural backgrounds play a role in unpacking these issues?”, and “How did your cultural background play a role in unpacking these issues?” This question serves to elicit teachers PCK of

SJSP, specifically with regard to the ways in which teachers engage in the problematization of the organizing SSI, and the ways in which they exhibit, and allow their students to exhibit, reflexivity with respect to the organizing SSI. This relates to RQ 1 because of the focus on teachers' PCK of SJSP.

The sixth question asks teachers, "Did you have any final paper, test, project, or culminating activity associated with the unit?", "What was it like?", "Why did you choose this activity in particular?" and "How, if at all, did this culminating activity extend student learning beyond the walls of the classroom?" This question allows teachers to describe the culmination of their SJSP unit of study, and how they supported students in elucidating their own position/solution with respect to the organizing SSI. This is related to RQ1 & RQ2 due to the focus on the agency & action domain of teachers' PCK of SJSP.

Question seven asks, "Tell me what you thought the students got out of the unit." This question serves to elicit teachers' PCK in terms of their understanding of students and student outcomes relating to their SJSP unit of study. Teachers' understanding of students, and the particular student outcomes teachers have in mind while planning, enacting, and reflecting on their lessons are an important part of their PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015; Magnusson et al., 1999)

Question eight asks, "Tell me how you thought the unit went. How would you change the unit if you were to teach it again?" This question allows teachers the opportunity to reflect on their unit of study and think through ways they would like to adjust it. This reflection on action is useful for eliciting teachers' PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015). As this reflection is centered around teachers' SJSP unit of study, this will help to answer RQ1, which focuses on teachers' PCK of SJSP.

Question nine asks, “Think back to a different group of students you taught, perhaps at a different school. What was different about this group of students? [probe for number of students, heterogeneity or homogeneity of class, student backgrounds and interests] How might you change the unit if you were teaching this group of students?” This question also asks teachers to be reflective of their SJSP unit of study, in particular thinking about how they would adjust their unit for a different group of students. This relates to teachers’ PCK of SJSP, in particular the domain of authentic activity, which will help to answer RQ1.

The final question asks teachers, “Is there anything else that I didn’t ask, but you feel would be important to talk about?” This question is not specifically aligned to any of the research questions, but was included to reveal possible aspects of teachers PCK of SJSP that they feel are worth talking about, but which were not anticipated by the researcher. This interview was collected from teachers at the conclusion of their second year of the J-STEM program over Zoom, and lasted approximately 60 minutes. With participants consent, the interview was recorded and transcribed. Teachers’ will be offered an opportunity to receive and review the transcript.

Artifacts

Yin (2018) points out that, while interviews are an important source of data in case study research, they are often insufficient for fully exploring the case. Collection and analysis of additional data sources, such as artifacts important to the case, can add richness and depth to the findings in case study research (Yin, 2018). Furthermore, “PCK can be found in the instructional plans that teachers create and in the reasons behind their instructional decisions” (Gess-Newsome, 2015, p. 36). As such, in this case study, the following artifacts related to teachers instructional planning were collected as sources of data: A) SJSP Unit of Study, B) SJSP Classroom Artifact & Reflection #1, and C) SJSP Classroom Artifact & Reflection #2.

SJSP Unit of Study. Throughout the course of the J-STEM program, teachers are guided to develop and implement a unit of study aligned to SJSP components. To support participants in developing their SJSP unit of study, teachers are provided a unit of study template (see Appendix A: Data Sources) that explicitly calls out the different components of the SJSP framework. This unit of study template is also aligned to the 5E learning cycle (Engage, Explore, Explain, Elaborate, Evaluate; Bybee & Landes, 1990) in order to provide a structure that is familiar to teachers. For example, in the Engage section of the unit of study plan, teachers are prompted to introduce students to both the authentic SSI, as well as the underlying STEM content. In the Explore section of the plan, teachers are guided to incorporate activities that support student modeling of phenomena related to the STEM content and SSI, and then situate this content within a social system connected to the organizing SSI in the Explain section. In the Elaborate section, teachers are prompted to engage students in reflective skepticism and perspective taking as they consider both the sociocultural and STEM dimensions of the organizing SSI. Finally, in the Evaluate section of the planning template, teachers are asked to plan activities designed to help students elucidate their own position or solution relating to the organizing SSI. This is aligned to RQ 1 because, through teachers instructional planning, their PCK can be made visible (Gess-Newsome, 2015), and as these unit plans are aligned to the SJSP framework, the PCK elicited through them will be PCK of SJSP. Additionally, this artifact is aligned to RQ 2, as teachers, through SJSP, were likely to plan activities designed to extend student learning beyond the walls of the classroom.

Specifically, the *Engage* section of the plan captured teachers' PCK of SJSP related to exploring the sociocultural context and grounding the STEM content in a phenomenon. The *Explore* section of the plan captured teachers' PCK of SJSP related to STEM content as teachers described how they engaged students in STEM modeling. In the *Explain* section of the plan, teachers continued to describe how they plan to engage students in the modeling process, as well as how they will guide students to understand the connections to different dynamic social systems connected to the organizing SSI, thereby eliciting their PCK of SJSP in terms of both STEM content and sociocultural contexts. In the *Elaborate* section, teachers described the ways in which they build students' capacity for reflective scientific skepticism and to compare and contrast multiple perspectives, which speaks to the problematization and sociocultural contexts domains of PCK of SJSP. Finally, in the *Evaluate* section of the plan, teachers described the ways in which they supported students in elucidating their own position or solution with respect to the organizing SSI, which relates to teachers' PCK of the agency & action domain of SJSP.

As teachers were working on developing and refining this unit of study throughout the J-STEM program, this artifact was collected in March near the conclusion of the teachers' second year of participation in the J-STEM program by the J-STEM research staff with prior IRB approval. Teachers have been working on developing their units of study since they began the Fall Institute of the J-STEM program, and implemented them in the spring of their first year. Teachers continued to refine these units of study over the course of their second year in the program. Throughout the program, teachers submitted their units of study periodically (2–3 times per school year) for feedback and for research purposes, with the final submission due at the end of March of their second year. Although teachers submitted their units of study at multiple points throughout the 2 year J-STEM project, I only used their final draft unit of study that they submitted at the end of their second year in March, as this was most relevant to my research questions.

SJSP Classroom Artifact & Reflection #1. The second artifact (see Appendix A: Data Sources) that was collected were student artifacts such as assignments, projects, essays, or videos that the teacher felt exemplified their learning of the organizing SSI and articulates the students stance on an issue of social justice. This artifact did not divulge any identifiable information about a particular student, and could just be the assigned artifact that the student would complete (for instance, just a project prompt & rubric without the actual student work filled in). This artifact was accompanied by a brief reflection by the teacher highlighting what they believe the student learned, as well as the students' challenges and the ways that students took a stance on social justice. This related to RQ 1 as it elicited teachers' PCK of SJSP relating to their particular students and particular outcomes of their SJSP unit of study (Gess-Newsome, 2015). Additionally, it related to RQ2 as well, as teachers' reflections on the artifacts had the potential to demonstrate PCK related to how students applied, or could apply, their learning outside of the classroom.

Specifically, as teachers were asked to "Select student artifacts (e.g. assignments, projects, essays, videos, etc.) that you think exemplify their learning of SSI and stance on social justice," the artifact was be related to the SJSP unit of study developed by the teacher, and as such be an artifact produced or selected through the lens of the teacher's PCK of SJSP. As such, it related to RQ1, which is concerned with teachers' PCK of SJSP in general. For example, in the first reflection question, teachers are asked to "Highlight and explain the components of SSI that you think the students learned. Please be specific." Teachers' understanding of student outcomes is an important aspect of their PCK (Gess-Newsome, 2015; Lee, 2016; Magnusson et al., 1999), and given that this artifact is related to teachers' SJSP unit of study, it was helpful in answering RQ1. Additionally, the following reflection question asks teachers to "What components of SSI are challenging for your students? Explain your answer." This question prompts teachers to reflect on aspects of the lesson that students struggled with, which revealed important aspects of their PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015; Magnusson et al., 1999). As such, this question helped to answer RQ1, which focuses on understanding teachers' PCK of SJSP. The next question asks teachers to "Provide examples that exemplify their stance on social justice. Explain your rationale." Similar to the last question, this question focuses on teachers' understanding of their students, this time with respect to the agency & action component, which is the focus of RQ2.

Finally, teachers were asked to "Describe what you would do next to help your students grow on their knowledge and practices on SSI and social justice." This question asks teachers to think about how they would support students with respect to their learning within the SJSP unit of study. The way teachers plan to deliver instruction is an important part of their PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015), and therefore served to help RQ1 and, depending on their answer, RQ2. This artifact and accompanying reflection (Appendix A) were collected at the end of the teachers' first year in the J-STEM program in May after they had successfully implemented their SJSP unit of study by the J-STEM research staff with prior IRB approval.

SJSP Classroom Artifact-Based Reflection #2. The third artifact (see Appendix A: Data Sources) that was collected was a reflection based on an additional student artifact such as an assignment, project, essay, or video that the teacher felt exemplified the ways in which student learning of SSI and students' stance on social justice was extended beyond the walls of the classroom. The student work artifact itself was not able to be collected based on the IRB decision, however the brief reflection by the teacher highlighted what they believe the student learned, as well as the students' challenges and the ways that students took a stance on social justice outside of the classroom was still obtained. Similar to the previously described classroom artifact, this will relate to RQ 1 as it is intended to elicit PCK of SJSP relating to their particular students and particular outcomes of their SJSP unit of study (Gess-Newsome, 2015). Additionally, this artifact will intentionally relate to RQ 2, as teachers were instructed to reflect on an artifact that demonstrates how students applied their learning outside of the classroom. Specifically, teachers were prompted to "Think of a piece of student work students completed as part of your USTRIVE Unit of Study (e.g. assignments, projects, essays, videos, etc.) that you think exemplify how students extended their learning of SSI and stance on social justice beyond the walls of the classroom. Answer the following questions with this student work in mind," and to "Highlight and explain the ways in which student learning extended beyond the walls of the classroom. Please be specific." This explicit focus on extending learning beyond the walls of the classroom relates to teachers' PCK of SJSP in terms of the agency & action domain, which is the focus of RQ2. Finally, as with the previous artifact reflection, teachers will describe what they see as their next steps to help the student deepen their learning related to SJSP. This will be collected in the Fall of 2023 after teachers' second year in the J-STEM program, having successfully implemented their SJSP unit of study. Selecting the artifact and writing the reflection took approximately 10-30 minutes, and teachers submitted this information asynchronously via a Google Form to allow them to do this at their own convenience and pace.

Table 1 below summarizes the data sources that were collected, including the timeframe, location, and research question alignment of these data sources. Additionally, data sources that were previously collected by the J-STEM research staff with prior IRB approval are noted as well.

Table 1

Data Sources

Data Source	RQ	Participants	Duration	Location	Schedule
J-STEM End of Year Interview [a]	1, 2, 3	3	60min	Zoom	Previously collected: March - June 2022
Reflective Interview on SJSP Unit of Study	1, 2, 3	3	60min	Zoom	NEW: Fall 2023
SJSP Unit of Study [a]	1, 2, 3	3	15min	J-STEM	Previously collected: March 2023
SJSP Classroom Artifact & Reflection #1 [a]	1, 2, 3	3	30min	J-STEM	Previously collected: May 2022
SJSP Classroom Artifact-Based Reflection #2	1,2, 3	3	30min	Google form	NEW: Fall 2023

[a] Data source was previously collected by J-STEM research staff with prior IRB approval.

Data Analysis

Data analysis procedures must be specifically tailored to fit the data source, research question, and research design (Creswell & Poth, 2018). As such, it is often more helpful to think of an approach to data analysis, as opposed to a specific protocol (Yin, 2018). To answer my research questions, I analyzed my different data sets using different forms of coding. According to Creswell & Poth (2018), coding is an essential analysis tool for qualitative data, and "involves involves aggregating the text or visual data into small categories of information, seeking evidence for the code from different databases being used in a study, and then assigning a label to the code" (p. 314). I used two primary approaches to code my data sources. The first was the use of theory-generated codes (Marshall & Rossman, 2016 p. 406) that align to the SJSP framework, and the second is through the use of open coding (Marshall & Rossman, 2016, p. 412) to make meaning and reveal themes and patterns in the data that are not dependent on a the previously described components of the SJSP framework. In order to fully capture the ways in which teachers express their PCK of SJSP, each data source was coded through both of these processes.

Specifically, this first step in the analysis process was to transcribe each of the interviews. While the J-STEM EOY interview was previously transcribed by J-STEM research staff, the transcript for the reflective interview was auto-generated through the Zoom recording feature, and was then edited by the researcher for clarity. Then, I read through each data source, noting theory-generated and emergent codes within each data source by placing excerpts from the data sources in a spreadsheet. Then, based on the number of excerpts that were noted as illustrating each code, the excerpts were reviewed and reclassified to either merge, separate, or remove codes based on the amount of evidence found for each one. Each of these codes was then aligned to one of the five domains of PCK of SJSP, and revisited to ensure the code still made sense in the context of the PCK of SJSP conceptual framework. At this point, these framework-aligned codes were then presented to another researcher with expertise in the field as a way of checking for coherence in the interpretation of this data up to this point. Codes were then adjusted slightly based on feedback received from this researcher. After this point, I reviewed and annotated each excerpt to ensure it still fit the code and that the code still fit the theme, adjusting excerpts and codes as needed. Finally, I memoed each theme by writing a longer narrative that connected each excerpt to the given code and the other excerpts representing said code.

Additionally, to address RQ3, which is concerned with how teachers' PCK of SJSP was expressed in ways that are both similar and different, I compared and contrasted the ways that each of the codes manifested, or did not manifest, within the data sources related to each individual participant. In doing so, I was able to compare and contrast their PCK of SJSP in terms of the teachers' reasoning process as well as the products the teachers created (i.e., units of study and classroom artifacts). To represent and summarize these similarities and differences, I created a table that noted whether or not each participant had expressed PCK relating to each of the themes revealed by the analysis process. This consisted of marking whether each code was present in the data for each code, and notating any particulars, such as focus, and whether the PCK in question represented an intention to enact some strategy in the future or an attempt to enact some strategy in the past.

Theory-Generated Coding Process

In order to capture the ways that teachers' PCK is expressed in terms of the SJSP framework previously described, the data sources were coded using theory-generated codes (Marshall & Rossman, 2016). In this process, I used the codes outlined in the SJSP framework to analyze and categorize each data source. These codes include Authentic Activity, Sociocultural Context (consisting of *exploration of SSI*, *consider issue system dynamics*, and *compare and contrast multiple perspectives*), STEM Content (consisting of *explore and explain the underlying scientific phenomena and/or concepts in mathematics* and *engage in STEM modeling*), Problematization (consisting of *employ reflective scientific skepticism*, *reflexivity*, and *dialogic conversation*), and Agency & Action (consisting of *metacognition* and *elucidate own position/solution*), defined according to the coding manual in Appendix B. Using these theory-generated codes allowed me to both find examples of teachers' PCK that fit these codes, and more succinctly analyze and describe teachers' PCK in terms grounded in the literature relevant to the conceptual framework of this study.

Open Coding Process

While a theory-generated approach to coding was both helpful and important in answering my research questions, it was equally important to engage in the process of open coding. Open coding allows researchers to look for emergent themes and patterns in qualitative data that may be useful in adding to an established framework (Marshall & Rossman, 2016). Engaging in open coding involves immersing oneself in the data, reading closely and noting themes and categories as they emerge (Creswell & Poth, 2018; Marshall & Rossman, 2016). Eventually, these themes and categories are combined to form more substantive categories that end up as the final codes. This process is not necessarily linear, as codes can be split and recombined at various points in the open coding process (Creswell & Poth, 2018). Ultimately, this was useful in generating codes that represent teachers PCK of SJSP and teachers PCK involved in extending learning beyond the walls of the classroom that were not fully captured by the existing PCK of SJSP framework, and thus presented the possibility of adding to said framework.

Interviews

J-STEM End-of-Year Interview. The J-STEM end of year interviews had already been transcribed by the J-STEM research team. Therefore, the first step in analyzing the collected data was to immerse myself in the data as I read through each transcript multiple times. While I read, I engaged in memoing, where I wrote down notes while reading describing any themes, ideas, patterns, connections to my conceptual framework, and connections to the other interviews. I also highlighted the evidence of these themes, ideas, and patterns in the transcripts. This helped me to keep track of my noticings as I immerse myself in the data. I then used the SJSP Theory-Generated Coding Guide (Appendix B) to find evidence of teachers' PCK of SJSP as described by my conceptual framework. After completing the theory-generated coding process, I used the notes and memos I had written to that point to engage in the open coding process. This interview was used primarily to answer RQ1, as it was best designed to capture teachers' PCK of the Sociocultural Contexts and STEM Content domains of the SJSP framework, although it had the potential to capture more being that it followed a semi-structured design (Galletta, 2013).

Reflective Interview on SJSP Unit of Study. This interview was analyzed in a manner similar to the above described interview, and was meant to elicit teachers' PCK of the authenticity, problematization, and agency & action domains of SJSP. The first step in analyzing this data was to transcribe the interviews. After transcribing the interviews, I read through the transcripts multiple times, immersing myself in the data, noting and highlighting ideas, themes, and patterns that emerged in connection with the previously analyzed data. After immersing myself in the data, I proceeded with the theory-generated coding process based on the PCK of SJSP coding guide (Appendix B), and then using the notes I gathered in relation to this data source, continued the open coding process. This analysis supported RQ1 by eliciting teachers' PCK of SJSP and RQ2 by focusing more explicitly on teachers' PCK relating to the Agency & Action domain of SJSP.

Artifacts

SJSP Unit of Study. The SJSP unit of study was analyzed by reading and re-reading the unit of study planning document to immerse myself in the data. Through this process of immersion, I noted and highlighted themes, ideas, and patterns that relate to PCK of SJSP, and then began the theory-generated coding process utilizing the SJSP Theory-Generated Coding

Guide (Appendix B). After completing the analysis process using the theory-generated codes, I engaged in the open coding process, making use of the notes and highlights I took at the beginning of the immersion stage, to re-analyze the data. This analysis supported both RQ1 & RQ2 by revealing evidence of teachers' PCK of SJSP in general (RQ1), and specific to Agency & Action (RQ2).

SJSP Classroom Artifact & Reflection #1. The data collected from this data source was analyzed in order to describe teachers' PCK of SJSP. The first step in the analysis process was to immerse myself in the data by reading and re-reading the data collected from this data source multiple times, taking notes and highlighting any themes, patterns, or ideas that jump out as relevant to teachers' PCK of SJSP. Once I immersed myself in this data, I began the theory-generated coding process making use of the SJSP Theory-Generated Coding Guide (Appendix B) to analyze the data according to the PCK of SJSP framework. Following this analysis, I re-analyzed the data, making use of the notes and highlights taken previously, using the open coding process to search for themes and patterns that reveal more about teachers' PCK of SJSP than could be captured solely through the theory-generated coding process. This analysis supported RQ1 by finding evidence of teachers' PCK of SJSP, and RQ2, by showing ways that teachers used their PCK of the Agency & Action domain of SJSP to plan activities that extended learning beyond the classroom for their students.

SJSP Classroom Artifact-Based Reflection #2. Data collected from this data source was analyzed similarly to the previous data sources. I began by immersing myself in the data by reading and re-reading the data multiple times, making notes and highlighting emergent ideas, themes, and patterns as they connect to teachers' PCK of SJSP. After immersing myself in the data, I engaged in the process of theory-generated coding using the SJSP Theory-Generated

Coding Guide (Appendix B) to capture teachers' PCK of SJSP present in this artifact-based reflection. Following this analysis process, I continued to analyze the data by utilizing the open coding process, making use of the previously taken notes and highlights, to illuminate the ways teachers' expressed their PCK of SJSP not fully captured by the existing PCK of SJSP framework. In this way, analysis of this data source supported both RQ1 and RQ2, by providing evidence of teachers' PCK of SJSP both in general (RQ1), and with respect to how teachers used the Agency & Action component of the PCK of SJSP framework to plan learning activities that extended beyond the classroom (RQ2).

After having analyzed each data source separately, I looked for areas of convergence and divergence these findings represent in teachers' PCK of SJSP in order to describe a fuller picture of teachers' PCK of SJSP as expressed through the planning of, development of, and reflection on their SJSP unit of study. By combining evidence from multiple data sources, I bolstered the trustworthiness of my findings through a process known as triangulation (Marshall & Rossman, 2016), described further in the following section.

Trustworthiness Criteria

As in any study, the degree to which the interpretations and meaning made from the data during this study can be considered trustworthy or credible is of paramount importance. One way to increase the trustworthiness in any research study is by ensuring the validity of the data sources (Merriam & Tisdell, 2016). Additionally, in qualitative research, this trustworthiness can be enhanced through triangulation (Marshall & Rossman, 2016). In the remainder of this section, I will first discuss the ways in which each of the data sources I collected can be considered valid measures of teachers' PCK of SJSP. I will then discuss the ways in which I employed triangulation to further enhance the validity of this study.

Validity

Validity is a term originating from quantitative research, but sometimes applied to qualitative research, that denotes the level of confidence one can have in the research findings based on the method of data collection, analysis, and interpretation (Merriam & Tisdell, 2016). Internal validity, sometimes called credibility in qualitative research, is the degree to which the research findings match reality, while external validity, sometimes called transferability in qualitative research, is the degree to which the lessons learned from the study can be applied to other contexts (Lincoln & Guba, 1985; Merriam & Tisdell, 2016). Yin (2018) notes how case study research often shows support for some theoretical propositions about a mechanism being studied, and that these propositions are what can (hopefully) be generalized to other situations. In my study, the mechanism is this conceptual framework PCK of SJSP described in chapter 2. In the remainder of this section, I will describe the ways in which I increased the validity of this dissertation research study in regards to each of my data sources.

Interviews

J-STEM End-of-Year Interview. The J-STEM end of year interview has been adapted from a similar interview used in a study exploring teachers PCK of SSI (Macalalag, Minken, & Varma, 2023), and revised based on input from other researchers in the field knowledgeable on the topic in order to incorporate additional components of SJSP that were not present in the initial PCK of SSI framework. This enhanced the validity of the data source because it has been previously established in the literature as a means for capturing teachers' PCK, which is what I used this data source to do. Additionally, both versions of these interviews were conducted by the same research assistant. This is important to note, as the researcher can also be considered an instrument (Creswell & Poth, 2018). Therefore, consistency in use of the instrument adds to the trustworthiness of the study (Merriam & Tisdell, 2016). As this instrument has been part of ongoing research projects, the instrument itself has already been tested and refined over time by a group of researchers to ensure that the questions yield answers that align up with the SJSP framework. This was done through analysis of the data yielded by J-STEM research staff, and making adjustments to the wording in different questions, and comparing the data yielded after using the instrument with another group of participants.

Reflective Interview on SJSP Unit of Study. The interview questions in this data source have been adapted from a previously validated instrument developed by Grossman (1990). The original instrument sought to better understand teachers' PCK by prompting them to reflect on a unit of study that they had developed and implemented in the classroom, which is similar to how I am using the instrument in this dissertation research study. The adaptations made to this instrument were to allow it to focus more clearly on the SJSP unit of study that participants have developed and implemented in their classrooms, and to provide a more specific focus related to the PCK of SJSP conceptual framework articulated previously in chapter 2. To further enhance the validity of this instrument, the specific questions were reviewed by researchers in the field prior to use with study participants. This added layer of review by qualified individuals served to enhance the validity of the instrument, as these individuals are knowledgeable in the areas of PCK, SJSP, and qualitative research methodologies. Similarly, peer examination of findings based on this data source also served to increase the validity of this data source. Peer examination involved discussion of research findings and interpretations with colleagues who can discern whether or not the researcher's interpretations of the data are consistent and appropriate given the actual data collected (Merriam & Tisdell, 2016). To further enhance the validity of this instrument, I recruited 2 participants who are also part of the J-STEM program, but who were not participants in my dissertation research study, to do a dry run with this instrument, ensuring that it captured data that are relevant and useful for answering my research questions, and adjusting the instrument as necessary. After analyzing the data from these two participants, I found that the questions functioned as intended, but that the interview took slightly longer than initially expected.

Artifacts

SJSP Unit of Study. Lesson planning is a common expression of teachers' pedagogical knowledge, and, as such, can be a useful measure of teachers' PCK (Magnusson et al., 1999; Minken et al., 2021). The lesson planning template used in this study is based on lesson planning templates previously published in the literature, and was designed to capture PCK of all the components associated with SJSP (Johnson et al., 2022; Minken et al., 2021). The SJSP framework this unit of study planning template was developed to illuminate has also undergone multiple revisions based on peer feedback from researchers, teachers, and an external advisory board familiar with PCK, SJSP, and research methodologies. All of this served to enhance the validity of this data source. Additionally, as this instrument has been part of ongoing research projects, the instrument itself has already been tested and refined over time by a group of researchers to ensure that the questions yield answers that align up with the SJSP framework.

SJSP Classroom Artifact & Reflection #1. Using artifacts from teacher planning and practice and asking them to reflect on it is a well-accepted and recommended strategy for eliciting teachers' PCK (Gess-Newsome, 2015). As this artifact and reflection will be directly related to teachers' SJSP units of study, it follows that it would be helpful in capturing teachers' PCK of SJSP. An additional manner of enhancing the validity of this data source was the use of peer examination (Merriam & Tisdell, 2016), which allow me to gain insight from other researchers well-versed in PCK and SJSP in the coherence of my interpretation and analysis of this data source compared to the data itself. Additionally, as this instrument has been part of ongoing research projects, the instrument itself has already been tested and refined over time by a group of researchers to ensure that the questions yield answers that align up with the SJSP framework.

SJSP Classroom Artifact-Based Reflection #2. Similar to the previously described classroom artifact and reflection, this artifact-based reflection provides evidence of teachers' PCK of SJSP by allowing me to analyze the ways in which teachers have rationalized the use of instructional resources developed in their SJSP unit of study. Just as with the other data sources, the validity of this data source was further enhanced through the use of peer examination (Merriam & Tisdell, 2016) by providing additional views and perspectives on the interpretations I made based on the data collected. Additionally, as this instrument stems from part of ongoing research projects, the instrument itself has already been tested and refined over time by a group of researchers to ensure that the questions yield answers that align up with the SJSP framework.

In addition to considering the validity of each data source separately, it is likewise important to consider how the use of multiple data sources together enhanced the validity of research findings through triangulation (Marshall & Rossman, 2016), which I elaborate on in the following section.

Triangulation

Triangulation can increase the trustworthiness of a study by showing how multiple data sources and analysis techniques support a common theme, assertion, or finding (Marshall & Rossman, 2016). In this study, I used multiple data sources, and multiple types of data sources to find evidence that answers both of my research questions. In this way, I enhanced the validity of this study's findings by drawing on multiple data sources to support each finding (Merriam & Tisdell, 2016).

Interviews

The interviews used as data sources for this study were designed to capture teachers' PCK of SJSP in different and complementary ways (see Table 2). For example, the J-STEM End-of-Year Interview was geared toward the Sociocultural Contexts and STEM Content domains of SJSP, while the Reflective Interview on the SJSP Unit of Study was designed to elicit teachers' PCK of SJSP relating to the domains of Authenticity, Problematization, and Agency & Action. By splitting these domains across two data sources, it enabled a deeper dive into each, as each interview took approximately 1 hour. Much like a statue illuminated by different light sources placed at different angles allows for a clearer view, the use of these multiple interview data sources can more fully capture teachers' PCK of SJSP, allowing a more complete and nuanced understanding.

Artifacts

While all of the artifacts have the potential to speak to all domains of teachers' PCK of SJSP, the SJSP unit of study is more comprehensive and holistic, while each of the SJSP classroom artifact-based reflections were more focused. While the teachers' are prompted to produce artifacts that meet criteria specific to PCK of SJSP, providing them multiple opportunities to do so can increase the chances of capturing their PCK, which has proven elusive in its measurement (Henze & Van Driel, 2015; Smith et al., 2018). This also provided confirmatory benefits similar to those of the interviews described above. Additionally, as each SJSP classroom artifact is accompanied by a written reflection, this provided an additional layer of detail that was be used to understand teacher's PCK of SJSP more fully.

Table 2

Triangulation Among Data Sources

	Data Source				
	Interviews		Artifacts		
PCK of SJSP	J-STEM End-of-Year Interview	Reflective Interview on SJSP Unit of Study.	SJSP Unit of Study.	SJSP Classroom Artifact & Reflection #1.	SJSP Classroom Artifact-Based Reflection #2.
Authenticity	x	**x**	x		x
Sociocultural Context	**x**	x	x	**x**	x
STEM Content	**x**	x	x	x	x
Problematization	x	**x**	x	x	**x**
Agency & Action	x	**x**	x	x	**x**

Note. Bolded x's represent primary domain(s) of PCK of SJSP targeted from each data source.

By utilizing not just multiple data sources, but multiple types of data sources (i.e., interviews and artifacts with written reflections), I was able to look for ways in which evidence gathered from each data source converged on common themes. Additionally, I employed two different forms of analysis for each data source. In doing so, I triangulated both by data sources and analysis methods to increase the trustworthiness of my potential findings. Specifically, analyzing my data through both theory-generated coding and open coding allowed me to verify that conclusions I am drawing based on the data were apparent through multiple modes of analysis.

Consent and Confidentiality Procedures

Participant safety is paramount in any research study. As such, I ensured that every effort was made to ensure participants had enough information to consent to participate in this study, and that participant identities remained confidential, both during the study and after it was concluded. Before participants consented to participate in this study, I explained to them, in writing using the communication script in Appendix C, and verbally as needed, my research questions and the nature of their participation, including time commitment and data collection activities. Participants were told that consent was voluntary and could be withdrawn at any point during the study. Additionally, participants were informed that their decision to participate or to abstain from my study had no impact on the relationship I have built with them to this point in my role as a J-STEM research assistant, nor would it impact their standing in the J-STEM program. Teachers who elected to participate in this study gave consent voluntarily by signing the consent form (Appendix D). At the beginning of each data collection session from all data sources, teachers were reminded that their consent is voluntary and can be withdrawn at any point during the study. Additionally, participants will be advised that, if they wish to withdraw from the study, any data collected up to that point can be destroyed at their request. The identities of the participants will be kept confidential, and will not be shared with anyone (outside of the dissertation committee chair). To this end, all data was de-identified, and reported either in aggregate or attributed to a pseudonym in any writings or presentations resulting from said data. Furthermore, de-identified data was stored on the hard drive of a password protected computer, and backed up in a password protected online storage system (Google Drive). Participants were permitted to request a copy of any data collected from them.

Chapter 4: Findings

In this chapter, I provide findings based on my data analyses guided by the following three research questions: (a) To what extent did teachers adapt their PCK of SJSP in the (re)development of a unit of study?, (b) To what extent did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom?, and (c) To what extent were teachers' PCK of SJSP similar and different as they (re)developed a unit of study? Based on my data analysis, the following findings emerged: Teachers exhibited PCK of SJSP across all five domains of SJSP (Authentic Activity, Sociocultural Context, STEM Content, Problematization, and Agency & Action). Teachers expressed PCK of Authentic Activity through the use and value placed on student voices, making learning activities relevant to students, and involving community partners in the SJSP unit of study. Teachers showed PCK of Sociocultural Contexts through their usage of SSIs and the ways they incorporated multiple perspectives within the SJSP unit of study. Teachers exhibited PCK of STEM Content through the practices of STEM modeling as well as collecting and analyzing data throughout their SJSP units of study. They also demonstrated PCK of Problematization in the ways they utilized the constructs of reflexivity, dialogic conversations, magnification, and comparative localization across their SJSP unit of study. Finally, teachers exhibited PCK of Agency & Action by guiding students to elucidate their own position/solution with respect to the organizing SSI, and through the use of community improvement projects within the SJSP unit of study. In the following sections, I detail findings across each of these PCK of SJSP domains, with special attention given to newly emergent components within each domain that were not present in the initial PCK of SJSP framework: Student Voice, Relevance to Students, and Community Partners (Authentic Activity); Data Collection and Analysis (STEM Content); Magnification and

Comparative Localization (Problematization); and Community Improvement Projects (Agency & Action).

"We can Plan Things, and Sometimes, the way that we Interact with the Kids, it Just Morphs into Something Different."

(Ms. Rossi, Reflective Interview)

I chose the above quote from Ms. Rossi to title this section of the chapter, in which I thematically describe the PCK exhibited by the participants in this study. This idea Ms. Rossi expressed at the end of our last interview intrigued me, and I saw multiple points of connection in terms of her particular experience teaching her SJSP unit of study with her students, in the ways that other teachers in this study (and some I know personally) talk about the act of teaching, in the way that research can result in emergent and unexpected findings, in the conceptualization of PCK (Shulman, 1986; Gess-Newsome, 2015) and in the ideals of SJSP itself. Essentially, it embodies what I feel to be the ideals and joys of education: that through interaction between and among educators and students, education truly comes alive.

PCK of Authentic Activity

While Authentic Activity was initially presented as a discrete idea, in analyzing teachers' PCK of Authentic Activity, three distinct themes emerged: the ways in which teachers valued and utilized student voices, the ways in which teachers made learning relevant to their students, and the ways that teachers engaged with community partners to add additional layers of authenticity.

Student Voice

One way that teachers expressed PCK of Authentic Activity was the ways in which they valued and incorporated student input and voices into their pedagogical practice. For example, when reflecting on his unit of study, Mr. Rubin shared that, for him "it's really about having a conversation about the topic, and that leads into the next lesson. If I can steer that conversation to my next lesson, then it's a success for me, and it's also a success for them because they are getting a chance to speak their mind and give their true opinion about the topic that's really affecting their lives" (Mr. Rubin, J-STEM EOY Interview). This shows the teachers' view of the importance of including not just opportunities for students to talk with one another, but to pull out the ideas they share in such discussions, using them to drive the unit forward. Ms. Moretti also shared that her teaching practices have shifted, with the teaching of her J-STEM Unit of Study, in terms of valuing student voices more. In reflecting on these shifts, Ms. Moretti states the importance of "not being scared to let the students take ownership over some of that. I think that's pretty much how my teaching has changed in terms of, you know, giving the students more of a say, giving the students more of a voice with those things that are affecting them all wrapped up in a pretty bow" (Ms. Moretti, J-STEM EOY Interview). This also shows the value teachers placed on drawing on students' voices and perspectives, integrating them into the unit of study.

Ms. Rossi also talked about the importance of student voices in how she conceptualized her initial unit of study about whether students should be able to charge their phones on public transportation buses, and how she designed her second unit of study focusing on the merits and drawbacks of speed cameras recently put in on a major highway near her school. In her own words, "I liked doing the unit both times. I liked doing the practice bus part. I liked doing the actual unit. I liked the second year I did the speed cameras one and the thing I liked about all that was there's so much work that went in to get it up and running but… it went well because it wasn't it wasn't like a thing that I was. You know….The students weren't just kind of like. Tumbling along in the stream of knowledge, they were kind of directing if they wanted to go there what they wanted to pull out of it. So I felt like there was more voice. For them and I felt like I got to hear more of who they were as individuals through this process than I normally would" (Ms. Rossi, Reflective Interview). Again, similar to the other participants, Ms. Rossi expressed the notion that students' voices and opinions were important in both moving the unit of study forward and how the unit of study unfolded.

In the same vein, Ms. Moretti reflected on how, when students interacted with the contents of her SJSP Unit of Study, this led to the unit being adapted, adjusted, and modified to more closely meet their needs. As she puts it, "Sometimes we can plan things and sometimes the way that we interact with the kids, it just morphs into something different. So I wouldn't have thought that there would have been like a big extension beyond understanding about fast fashion is not equitable for water, right? And how it's polluting the waterways and stuff and it's not really, I don't wanna say it's not affecting us over here, but it tends to be countries that are more poor or more overpopulated and stuff. And I think letting the kids develop their own kind of spin on that… I want to delve more into that. It would have been nice if it could have turned into a couple of units. And go on a little bit further, like maybe looking at policies of different countries or how that could be teased out a little bit more about working conditions of workers and money and things like that. I think that's something I would have liked to have been able to do." (Ms. Moretti, Reflective Interview) In fact, Ms. Moretti notes here the importance of incorporating student voice into these units of study and the desire to do so even more in the future.

Relevance to Students

Another theme that emerged from data analysis was the ways in which teachers used relevance to students as a way to bring authenticity into their SJSP Units of Study. Teachers made learning relevant to students by using local examples related to the SSI and leveraged their understanding of students when planning their units of study. For example, as Ms. Moretti reflected on her experience developing and implementing her unit of study over the course of the J-STEM program, she noted:

> I think that one of the really cool aspects of the program is how everything is definitely based on [this city and the surrounding] area. And having the student experience be one that is Oh, wow! Like That's my city or I know that location and different sections of the city like a lot of this stuff we talked about just didn't come from one central location. (Ms. Moretti, J-STEM EOY Interview)

One of the first things that sparked Ms. Moretti's interest in the J-STEM program is that it was very particular to her locale, and the locale in which she taught. In addition, she was excited by the fact that examples came from a diverse collection of neighborhoods within the city, expressing that the geographical proximity to students adds relevance that made for a more authentic experience.

> [Professional Development facilitator with a different program] just– I was on the water works program yesterday, and she talked about, and you guys have done this. I forget what it's called, but like when you have something and you can like toggle it back, and it shows like a map or something. And then when you pull it over, it shows a different part. Well they were showing the different schools of this people like us that are involved. They're doing projects about our watershed and seeing that was like, Oh, my God, like I didn't even know that. (Ms. Moretti, J-STEM EOY Interview)

Here Ms. Moretti notes the importance of having data and tools that can reveal information about different areas of the city, connecting that to the schools different students attend. Again, much of her enthusiasm seems to come from the fact that the examples she was seeing were relevant to her own students based on geographical location. As she continues, she points to what she feels are benefits of incorporating relevant examples into learning:

> So finding out the history of your school in your area, and what it was, and what that watershed looks like. and then being able to make that connection back to what we talked about with West [City] and the golf course and the flooding and the things that happen. I think that those things are definitely beneficial because a lot of the time I think that with certain areas of this city we only hear of one particular type of talk about the area that hearing something else like Oh, i'm in North [City] but i'm still part of a watershed. I want to learn about that. And why shouldn't I do certain things? and how that can affect my community, and in essence myself. I think that when you all made those connections with the articles and things like that really was powerful because it directly affects you know the kids that are involved. (Ms. Moretti, J-STEM EOY Interview)

Here Ms. Moretti expresses how the use of local experiences and examples were important in making the unit of study impactful for students. Similarly, Mr. Rubin noted that, when implementing his unit of study around water quality and the value of store-bought plastic water bottles, students became more invested in "testing the samples inside the school because that's what they want to know. They want to know how safe the water is to drink" (Mr. Rubin, J-STEM EOY Interview). Again, this shows the importance of selecting an SSI, and translating it into a unit of study, in such a way that it will be relevant to students.

Teachers, also aware of the importance of making learning relevant to their students, were able to leverage their understanding of the students they teach in order to plan units of study that would be more relevant to their students. For example, within her unit of study "Should we save the zoo? Understanding electricity, power grids, and power outages in [City] using the Texas

Energy Crisis of 2021 as a model", Ms. Rossi notes that "Electricity and access to electricity to charge their phones is a central cog in decision making. Students have confided that they change how they travel and where they go in order to charge their phones. We will leverage this for the debate" (Ms. Rossi, SJSP Unit of Study). While the content for this unit is around electricity and the ultimate SSI is around the value of caring for zoos in the event of an energy crisis, Ms. Rossi taps into her understanding of the students she teaches to draw on their values related to electricity, in this case, the importance of cell phones, in designing her unit of study. Ms. Rossi also shows awareness of students' experiences on this topic, noting that "Students will have personal experience with power outages, electrical malfunctions and the circumstances that caused electronics to get hot or break" (Ms. Rossi, SJSP Unit of Study). Similarly, Mr. Rubin acknowledges the experiences of his students in his unit of study on the value of bottled water vs. tap water, stating that "most students use plastic water bottles every day, taking them to school for convenience and filling them up at water stations before throwing them out at the end of the day" (Mr. Rubin, SJSP Unit of Study). He also reflects on the importance of understanding his students and and being aware of their backgrounds, saying in an interview:

> I think that most of my students come from economically challenged backgrounds. And I think that the perception that a lot of my students have is possibly that mid-level/low level, let's say, income, areas that …that water consumption might be linked to poor tap water quality and often unreliable public water systems. So, I don't know if that is the actual thought process, but, by going around my room in engaging that, there are out of 25 students about 17 to 18 students have plastic water bottles that are the ones that they get from the store says a lot about what the thought process might be. (Mr. Rubin, Reflective Interview)

This shows how Mr. Rubin is thoughtfully engaged in reflecting on the experiences his students have outside of the classroom, and how that translates to behaviors and experiences inside the classroom. Ms. Moretti also showed her understanding of students related to her unit of study, writing about students' prior experiences with the content and with the sociocultural systems that content is situated within:

> Students should have a basic concept of the water cycle. Students should understand the concept of water run-off. Students should know that they need to be clothed and hence, have experience buying clothes. Students should be able to understand what is a fashion trend…Students already understand that clothing is a necessity of life. Some students might know the expense associated with clothing, others might be aware of the prestige of name brand versus cheap clothing. (Ms. Moretti, SJSP Unit of Study)

By including these understandings in their unit of study, the teachers illustrate their intention to build on such student experiences and values in designing their lessons.

Teachers in this study acknowledged that making their units of study relevant to students' lives was important for engaging their students in the learning process. As Mr. Rubin puts it:

> it's really about getting students involved in topics that have meaning to them and affect their lives. And with social justice, it's about treating all students with equity so that they feel safe and secure…. sometimes students don't feel that way because of issues that don't affect them. That's why it's important to introduce a science topic that will affect not some of the students, but really all the students. (Mr. Rubin, J-STEM EOY Interview)

This shows the teachers' belief that the topics students can engage with in an SJSP unit of study will be meaningful and therefore more engaging to students. He continues, cautioning that "if a teacher thinks that something is important, it might not be important to the students, and that's where you get ‘turn off’ from students” (Mr. Rubin, J-STEM EOY Interview), which also shows the link he sees between relevance and student engagement.

Ms. Moretti also spoke about the importance of selecting a SSI topic that would be relevant to students. In describing the implementation of her own SJSP unit of study around fast fashion, she notes:

> leveraging it, I think was really coming from the students because so many of my kids had connections of their own family. Between family members coming from countries that, you know, learning about and the things that they brought to class. So I didn't have to do any heavy lifting of that. The kids really were just very interested. (Ms. Moretti, Reflective Interview)

Here, Ms. Moretti notes how students’ prior familiarity with the content and the SSI, particularly in terms of relevance to students and their families, allowed for less effort on her part to engage the students, as the students already felt connected to the topic.

Ms. Rossi likewise notes a link between making content relevant to students and her students’ engagement with that content. In comparing what she calls her pre-unit SSI relating to the recent development of placing speed cameras on a major highway near the school, she said that:

> Well, actually the speed cameras on Roosevelt Boulevard were a lot higher interest for my students. The idea is the idea of street racing and getting caught and not getting caught by the police, I think was way more engaging,but when I did that pre-unit it was almost too engaging because every conversation kind of like came back to that gravity instead of going into the science. So, that was high interest for my students. (Ms. Rossi, Reflective Interview)

Ms. Rossi's experience shows the high potential for engagement when bringing in topics and examples that are related to students experiences and interests, as well as the need to manage and plan for that engagement when designing lessons in this way to appropriately channel students' engagement and excitement for a topic into the teachers' planned learning activities.

Teachers also described the importance of adjusting their units based on their student population. In particular, Ms. Moretti described the importance of modifying her unit of study based on students' interests and backgrounds when reflecting on different student populations she has taught in the past (in particular at a school with predominantly Hispanic students, as compared to her current school with many students who immigrated from European countries). She says:

> I think if I were teaching that particular group of students, I wouldn't have focused so much on European countries. I would have, you know, focused a lot, like a lot of the articles that I selected were highlighting and or came specifically from, you know, Eastern Europe because that's what the predominant amount of my kids were from. I think I would have tried to have them do a little bit more research in terms of Spanish and Hispanic populations and how it affected them like maybe in Guatemala some things that were happening in terms of like you know sweatshops and laborers and stuff like that. You know, things happening down in Mexico. I'm trying to think of places that my kids were actually coming from… of course, Puerto Rico... So I probably would have focused a little bit more about things that were more concentrated for them. (Ms. Moretti, Reflective Interview)

Here Ms. Moretti describes how her understanding of students' backgrounds contributes to her planning relative to her SJSP unit of study. Ms. Moretti also shows how she values having knowledge about her students and their backgrounds, seeing it as important to planning successful lessons. As she continues to reflect, she points out the ways in which the particular diversity of her student population led her to look at practices in specific countries relative to her SSI:

> Because [my school] is so diverse. And we have such a… this lesson morphed out of… I wanted to study is there equitable access to like toileting in other countries because I had specifically read about you know in India a lot of the times the, you know, toilet or whatever you put it right outside but then and the wastewater carries it down to the streams and stuff. It was an article that I had read. I don't remember what it is now. But then, you know, in talking with [a J-STEM facilitator] and stuff, kinda got teased out. To kinda like, oh, what about this? And I was like, oh, that sounds really good. And then it just became something. So that's kind of like how the whole, you know, European vibe came about. And especially since my kids have so many connections to that. But I know for a fact that my kids at [previous school] would have had a lot of the same connections because, you know, a lot of the grandma's were still doing sewing and stuff like that in order to make additional money in the home. (Ms. Moretti, Reflective Interview)

While Ms. Moretti notes certain common themes among student backgrounds and their likelihood in engaging with the SJSP unit of study as written, she also notes the importance of changing some of her examples and assignments to more closely align with the backgrounds of the students she intends to teach.

Community Partners

Another way in which teachers in this study exhibited PCK of Authentic Activity was the ways in which they sought out and engaged with community partners over the course of their

SJSP units of study. One such way was by bringing community partners into the classroom to work with students. For example, Mr. Rubin noted in his lesson plans that “Through a collaboration with the Tookany/Tacony-Frankford Watershed Partnership; students will conduct watershed activities during an in-school setting. This is accomplished through a Creek Mobile brought to the school.” (Mr. Rubin, SJSP Unit of Study). This speaks to the value Mr. Rubin sees in bringing in community partners to engage with his students. Mr. Rubin further reflects on his experience with community partners, saying

> I partnered with the [City] Water Department, and the [City] Water Department actually came in and they did a whole lesson about plastics, particularly microplastics, and what effect that it has on society and what effect that it has on the environment and specifically animals per se, and how plastic really doesn't necessarily break down in a short amount of time. (Mr. Rubin, Reflective Interview)

Mr. Rubin's reflection here shows that bringing community partners in to work with students provides an avenue for students to engage with real-life issues of scientific importance related to the overarching SSI in Mr. Rubin's unit of study about tap vs. bottled water.

Ms. Moretti also saw value in bringing in community partners to engage with students. In her SJSP unit of study, Ms. Moretti notes that

> we actually had a guest speaker who wrote a book called Janj. And she came over and they were having conversations about how they gather water, you know, and how it's a very, very, scarce commodity for some people because you can't just go and get the well water. Well, you have to do a whole bunch of stuff to it. So for them, they're like, oh, well, that's a lot of usage. So it was interesting being able to have all those ideas come

> together, you know, we're talking about the diversity of the class. (Ms. Moretti, Reflective Interview)

By bringing in the community partner, in this case a guest speaker, Ms. Moretti was able to add authenticity to the unit of study by creating a dialogue within the classroom based on the speaker's and the students' life experience related to the overarching SSI in Ms. Moretti's unit of study about fast fashion and the role of water.

In addition to bringing community partners into the classroom to do workshops or as guest speakers, Mr. Rubin also built into his SJSP unit of study opportunities for students to work with community partners outside the classroom. In this way, Mr. Rubin built authenticity for his students by exposing them to equipment and materials that he did not have in his own classroom, but which were commonly used in the field. As Mr. Rubin puts it

> One other thing that we did as part of our unit was we took a trip to the Fairmount Waterworks. And at the Fairmount Waterworks They have something –and I want to get this from my class and I I really need to get this– I believe it was called Infinite scope and what. Happens is there's a tiny little water sample. And they put it in like a little – it looks like a funnel. And but it's closed at the end of it. And that sample then is kind of fed into a mechanism that goes over the camera of an iPad. Kind of like –and it creates like a microscopic effect And from there, they launch an app and they can see organisms –literally live organisms crawling across the screen. And seeing organisms inside the samples. And the students thought, oh my gosh, if that's in the samples, then that's not good. But the way it was told to my students was actually that's really good. Because that's showing that the water is actually healthy. If there weren't any living organisms. Then it would show that there's certain levels of chemicals that are in the water that are

> not safe. And that no living thing could. Be in the water. So that was really interesting. They were blown away by that. (Mr. Rubin, Reflective Interview)

Here, Mr. Rubin notes the connection between having students engage in authentic activities facilitated by the community partners and his students' propensity for engagement and understanding realized through this process.

It is also important to note that, while not all teachers in this study successfully involved community partners, both Ms. Moretti and Ms. Rossi expressed their intention to involve community partners in future SJSP units of study. For example, when asked to describe what they would do next to help their students grow on their knowledge and practices on SSI and social justice, all participants referenced community partners. For example, Ms. Moretti stated "I would help connect them with partner groups/organizations who could help them bring their ideas to fruition." (Ms. Moretti, Classroom Artifact-Based Reflection #2). This illustrates the value of community partners in turning students' ideas into a reality. Ms. Rossi also noted her intention to bring in community partners, expressing that "I wanted to and still want to connect my students with community partners because I want them to feel confident to reach out to partners as adults and not fall back into letting the world wash over them." (Ms. Rossi, Classroom Artifact-Based Reflection #2). Here, Ms. Rossi notes the importance of using community partners to help students build confidence and agency by connecting them to the world outside the classroom through authentic experiences. Ms. Rossi also expresses her intention to work to find community partners to bring into the classroom for her SJSP unit of study in the future. As she puts it, "I'd also hope to do like a little bit more like research and finding people in the community that work in equity and electricity and equity and power generation" (Ms. Rossi, Reflective Interview). This also highlights the challenges that teachers can face in finding and securing community partners to involve in their units of study.

It also is worth noting that teachers can use community partners to engage students in projects designed to improve students' own communities. For example, as Mr. Rubin reflected on his SJSP unit of study, he noted that

> I would not only get my immediate students involved in a short unit on SSI, but would make it a larger point of advocacy in their school/community. Marking storm drains was an excellent way for my students to bring awareness to the community, but I need to partner with organizations to get the school involved in ways to bring this SSI to light. I think I would also have my students do their own research project and then have a real debate in front of an expanded school audience. (Mr. Rubin, Classroom Artifact-Based Reflection #2)

As Mr. Rubin expressed here, community partners can also help students in engaging in community improvement projects, where students engage in some action with the intent to improve their community (e.g., school-community, neighborhood-community, etc). This theme, as seen in the data, will be discussed later on in this chapter in the context of teachers' PCK of Agency & Action.

PCK of Sociocultural Context

In examining teachers' PCK of sociocultural context related to SJSP, I saw unique and nuanced ways that teachers' made use of SSIs and multiple perspectives with their students.

Socioscientific Issues

In analyzing participant data, participants revealed ways and reasons for incorporating socioscientific issues with students. For instance, Ms. Rossi chose to blend social issues with

STEM content by introducing the content first, and then layering on social issues in order to add complexity and context for students. When describing her approach, she indicated:

> I think it would be kind of like a two pronged attack where we would go back and we would look at very specific kind of information about like particles, particle size, and how long they stay in the air. Because I think, I think that there might be misconceptions in like you know once you leave a room those particles are no longer there or if you come into a room the particles are clean, so I think we might have to branch into that and that would be the first prong. And then I think the second prong would be an idea of weighing mobility and choice four people, and like what inconvenience means for some versus what life threatening means for others. (Ms. Rossi, J-STEM EOY Interview)

Here, Ms. Rossi is beginning with STEM content, specifically analyzing particle density and size and how that affects their movement in terms of spread of disease, and then layers on social concerns such as health issues to add nuance and complexity to what could otherwise be a more abstract concept. She elaborates on the important ways she would guide students to examine the sociocultural context surrounding this issue:

> So I think we would look at, you know, if you only have one caregiver in that caregiver has breathing issues is that the same as someone who has a whole family, and how does it change if you only have that one caregiver, and what are you thinking about if you only have that one caregiver, or if you only have one if you'll have a sibling that has breathing issues, so I think we would kind of go in that route to to talk about how disproportionate it is between feeling maybe optional versus how life threatening it can be. (Ms. Rossi, J-STEM EOY Interview)

It is also worth noting the way Ms. Rossi expresses here that fully understanding an SSI involves looking at it from different vantage points. This theme of multiple perspectives is elaborated on further in the following subsection, but is mentioned here to draw attention to the overlaps that sometimes exist within teachers' PCK of SJSP. Ms. Rossi's response to this hypothetical scenario is consistent in how she applied her PCK to the SJSP unit of study she actually taught, in this case relating to tough decisions in the face of an energy crisis:

> I chose physics as my content area. And my unit was based on electricity. Well, that was the first unit I wrote. And then, So what we did was we kind of connected. Electricity as both a physical science and a physics concept back to the power crisis that happened in Texas. So students started by learning a little bit about circuits in general and then we kind of connected that back to what a power grid is. And we identified the problems in the Texas Crisis. (Ms. Rossi, Reflective Interview)

Here, again, Ms. Rossi started with the STEM content, in this case electricity, and then layered on social applications and considerations, drawing connections to existing social phenomena, in this case a contemporary energy crisis being talked about in local and national media.

Another participant, Mr. Rubin, notes the care that is needed when considering and selecting social issues to pair with STEM content, highlighting the importance of SSI in making content relevant to students. As he puts it, "I think it's really getting into the heads of our students to understand what effect in their daily lives how they can change their community, uh, that this topic that would have an impact on them and their community." (Mr. Rubin, J-STEM EOY Interview) These considerations were important to Mr. Rubin in choosing the SSI he would use for his unit, ultimately settling on the merits of tap vs. bottled water. Reflecting on these choices, Mr. Rubin states "Those decisions were made because they have an impact on those students' lives since they frequently drink water from plastic water bottles" (Mr. Rubin, J-STEM EOY Interview). While Mr. Rubin is clear on the importance of utilizing SSI to make STEM content more relevant engaging for students, Ms. Rossi also brings up the importance of SSI in connection to tackling issues of injustice in the classroom:

> So I think the biggest thing is is that idea that science can frame a lot of important arguments and that scientific information and data doesn't necessarily give you one answer, but it's important to kind of sketch out what the problem is and the complexity of the problem, and I think specifically this year the big change was kind of embracing the complexity instead of trying to find you know like a clear cut answer or a resolution just to kind of embrace the complexity as a part of the evolving social justice paradigm. (Ms. Rossi, J-STEM EOY Interview)

It is important to note here the link participants see between making content relevant and engaging and engaging students in problem solving around real-world issues of injustice as part of developing and implementing their SJSP units of study. One of the ways in which teachers engaged students in considering the social issues related to the STEM content they were learning was through the act of perspective-taking, discussed in the following subsection.

Multiple Perspectives

One way in which teachers in the J-STEM program engaged students in considering a multitude of viewpoints was through role-play activities in which students took on the viewpoint of an assigned stakeholder related to the overarching SSI around which the SJSP unit of study was organized. For instance, Ms. Moretti describes how she would enact this approach to help students understand the nuance and complexity regarding mask-mandates, a sometimes polarizing issue:

> You kind of just have like a big like chart paper, and you know, like reasons people might not be able to wear masks, and each kid would have like a different color marker, and they would put their reasoning on there like, Well, why do you think that you know a teacher and authority figure might not be wearing the mask. is it choice? Is it defiance? is it you know that authority power trip of like Okay, Well, on the adult I don't have to you know do that to see kind of like. where they're coming from, and what their thoughts are, and then have the kids share out and then discuss their own ideas in terms of you know, like what perspective are they coming from, and you know like are there different perspectives. maybe even role play like you know what's a – what would be a reason why somebody wouldn't wear a mask? But that's kind of like the thing that pops into my head in terms of like what I would do. If I were the teacher in the room I would just have them, you know, do that paper, and then people could do like a gallery walk and see what the different perspectives are, and what the students say to different reasons are. (Ms. Moretti, J-STEM EOY Interview)

Ms. Moretti's reflection here shows her belief in how such multiple perspective role-play can aid in students understanding multiple points of view, and thus inform their own. Similarly, in thinking about how to help students understand capacity limits in restaurants and their value in stopping the spread of infectious disease, Ms. Rossi explains how

> I would definitely have the students kind of talk about the different roles and you know I think I would do a similar thing where you know we asked [the city] to enact a policy and then you know there would be rules that the students can choose but then they have to find a majority to pass the policy, to kind of have them understand the complexity of the issue because there is, you know, the waitress and the restaurant owner and the waiter and

> the bus the bus person they're they're [city transportation] because you got someone driving people to these places or not there are people that want to go out people that don't, so I think trying to get all those different personalities and to their heads that they see the complexity and then they also see the value in trying to communicate as their role and then find a majority to move forward and kind of solve the problem. (Ms. Rossi, J-STEM EOY Interview)

In this way, Ms. Rossi hopes to guide students toward making sense of an issue while respecting and appreciating the issue's complexity, and how any potential resolution of the SSI would impact different people in different ways. Ms. Rossi uses a similar activity in her SJSP unit of study about the ethics of saving zoo animals during an energy crisis. An excerpt of her unit of study reads:

> students select roles, Write a draft of a speech answering the scenario question: Should we save the zoo?
>
> Fill in the graphic organizer and prepare for a 2-3 minute speech at an emergency city council meeting based on your role.
>
> It is February 14, 2023. The power is out due to extreme cold and citizens are worried it could last for more than a day. The Zoo has asked that power be first restored to the zoo to save some animals unaccustomed to the cold.
>
> Fancy Hotel Director- ; Realtor/developer owning 17 rental buildings in North and West [parts of the city] -; Hospital Administrator--; Religious leader with a building that offers a warm space and free hot breakfast to the community 6 days a week- ; Zoo director-; Community Block Captain in [neighborhood]-; Electrical Line worker or Electrical line worker Union; Leader; [Public Transportation] Director-; Police Officer- ; [School

> District] Superintendent-; Ambulance Driver- ; Nursing Home Director- ; Tax Paying Citizen with 3 children and 1 elderly parent/grandparent (Ms. Rossi, SJSP Unit of Study)

It is interesting to note here that Ms. Rossi structures this activity as more than simply a round-table discussion, and includes scaffolds for students such as graphic organizers and a required product to keep students focused on the learning task. In reflecting on the value of this activity, Ms. Rossi shares that

> [students] were assigned a role and the question was should we save the zoo and then They all said yes in the beginning that we should save the zoo if the power went out. But then as I gave them their roles, they found out that their roles wouldn't say yes to saving the zoo because there were other social they discovered other social requirements based on their rule. (Ms. Rossi, Reflective Interview)

Here, Ms. Rossi notes how the addition of multiple perspectives into the unit of study lead to deeper, more nuanced learning for her students.

However, endeavors in perspective-taking are not without their challenges. Ms. Moretti reveals that tuning into the perspective of others was sometimes difficult for her students:

> Some of my students had a hard time putting themselves in the place of other people or groups of people. Other students had first hand understanding of the equitable practices of the fast fashion industry as they come from countries where they had direct family members who worked in fast fashion factories. So the direct understanding to how it effects clean water based on personal experience had a quicker impact on some than those who it hadn't affected before. (Ms. Moretti, Classroom Artifact-Based Reflection #1)

This potential difficulty in perspective taking seems to stem from students' proximity to the SSI, as the students in Ms. Moretti's class who had more experience, directly or through family members, seemed to be more willing to consider alternate viewpoints. Mr. Rubin expressed his intention to improve student success in exploring multiple perspectives by bringing in stakeholders to speak to his students regarding the SSI:

> Next time, I would arrange to bring in person (or through a virtual video conference) representatives from the water department or water treatment facility, or an actual scientist that works exclusively on water testing to explain to my students the difference in drinkability of tap water vs. bottled water. (Mr. Rubin, Classroom Artifact-Based Reflection #2)

It is interesting to note here the overlap between Mr. Rubin's PCK of Sociocultural Context (having students consider multiple perspectives) and his PCK of Authentic Activity (bringing in community partners). As shown in the SJSP framework (chapter 2, Figure 1), Authentic Activity is central to SJSP, so it is not surprising to see the overlap here, with Mr. Rubin using community partners (Authentic Activity) to help students consider multiple perspectives (Sociocultural Context).

PCK of STEM Content

In analyzing teachers' PCK of STEM content, I saw teachers relying on the process of modeling, as well as an emphasis on data collection and analysis, in facilitating student learning.

STEM Modeling

In teaching STEM content, participants used models with their students in various ways. For example, Ms. Rossi opened up her SJSP unit of study about tough decisions during an energy crisis by having students make an initial model of an electric circuit using an energy ball:

> We started the opener was a group activity. I learned from code.org to kind of do like a hands-on thing to level the playing field. So some of my students knew a lot about electricity and some of them knew nothing other than they plugged in their phone. So we started by using energy balls and We talked about how to make a circuit and when the energy ball worked and then we tried to build the biggest circuit possible. And then from there we went on to studying Circuits in PHET and using snap circuits. And then after that we started getting into the socio scientific part. (Ms. Rossi, Reflective Interview)

This was important for Ms. Rossi in providing her students with a common experience relating to electricity that they could build on throughout the rest of the unit of study. As seen in Ms. Rossi's lesson plan, the use of energy balls allowed students to build on and revise their own conceptual understanding of how energy and electric circuits worked by quickly revising their physical models:

> Students will interact with an energy ball to build their first mental model of electricity. They will build up from a few students and see how big the circuit can be. They will be able to rapidly design little tests to answer their own curiosities and build their understanding through those choices. (Ms. Rossi, SJSP Unit of Study)

In addition to constructing physical models, participants such as Mr. Rubin had students engage with computer models in order to understand environmental processes:

> I had them look at Google Maps so we could take a virtual field trip to the Tookany Creek, we also looked at maps to see tributaries of how the water dumps into the Delaware river and then in to the Atlantic Ocean, so looking at the effect of how plastics can pollute and the effects that has on marine life. (Mr. Rubin, J-STEM EOY Interview)

Through the use of computer models, Mr. Rubin helped students to understand the impacts of pollution related to his SSI (tap vs. bottled water). Similar to Ms. Rossi, Mr. Rubin's purpose in having students use models is in building student understanding of scientific phenomena. Ms. Rossi likewise notes that models employed for this purpose can work equally well whether they are physical or computer-based. In her lesson plans, she provides for both options:

> Students will have their choice of using PHET or a Hands on Model to build and observe the behavior of circuits. Students will build up from the energy ball model to a working model. When students engage with phet they will be asked to focus on what makes the system break. (build a circuit, try every piece, make a fire, fix the fire-add a screenshot to your notebook with and without a fire) When students engage with snap circuits they will be asked to focus on successful circuits. One snap circuit jumbo kit will be available for super engaged students to continue building knowledge. That kit will be available for the rest of the year. Students will be asked to make quick explanatory videos for each tiny project- they can use the book provided and demonstrate the circuit they made. Alternatively: students can all build with phet before the town hall and use snap circuits after the town hall. The snap circuits make a powerful and empowering mini project if you have more time. (Ms. Rossi, SJSP Unit of Study)

In this case, students are interacting with models to find failure points that can cause the system in question to break or shut down. This is important in resolving the central SSI in Ms. Rossi's unit of study surrounding energy crises, as Ms. Rossi's goal for students in modeling this phenomenon is to help them understand how electric circuits can behave and become overloaded in large-scale systems that communities depend on. As she elaborates in her lesson plan, "The idea of having a closed circuit is central to understanding how the electrical grid is built. We will build a simple circuit and use that model as we build an understanding of the larger energy grid system" (Ms. Rossi, SJSP Unit of Study). Modeling, here, is key to furthering students' conceptual understanding of the larger system.

Data Collection & Analysis

Another way that teachers expressed their PCK of STEM Content was through the ways in which they engaged students in collecting and analyzing data. While the term data can mean different things in different contexts, in this subsection I use the term to refer to experimental or observational data, whether collected by a third party or by the students themselves. One participant in particular, Mr. Rubin, used data quite a bit to help students understand STEM content relating to water quality. His lesson plans show one lesson in which "students use a water analysis kit to test levels of 8 common water quality conditions in order to see which samples are safer to drink - bottled or from the tap." (Mr. Rubin, SJSP Unit of Study). He then has "students work in groups to complete the data sheet and then debate about which water source would be safer to drink" (Mr. Rubin, SJSP Unit of Study). This shows the value Mr. Rubin places on having students collect and analyze data to support a claim (in this case, which water samples are safe to drink). Additionally, his use of group work shows the value he places on having students work collaboratively to make sense of the data. As Mr. Rubin explains,

> We also used water testing kits in our classroom to check out the total dissolved solids from different water sources: from two different types of bottled water, tap water, uh, tap water that's used at our water fountains right in school. And we also used water analysis kits showing levels of copper, iron, chlorine, nitrates, nitrites, and a whole lot more and had our students really understand what's in the water supply, what's in the local water, and why there's chlorine even in the water. (Mr. Rubin, J-STEM EOY Interview)

It is important to note here that Mr. Rubin is also showing PCK of Authentic Activity (Relevance to Students) by choosing water students may be consuming at their school. This makes sense, as mentioned previously, due to the fact that Authentic Activity is at the center of the SJSP framework, permeating the surrounding four components.

In addition to making use of data collected by students, Mr. Rubin also has students analyze data collected by a third party. Included in his lesson plan is an activity in which "Students look at the EPA Plastics Table and Graph data from 1960-2018 to see how much plastic has been generated and recycled" (Mr. Rubin, SJSP Unit of Study). This is important because it shows the value of analyzing and making sense of data gathered by others in addition to data gathered by students themselves. In fact, by incorporating both types of data, it is possible for Mr. Rubin to connect the practices his students engage in with those of "real scientists" working in the field, perhaps strengthening his students' ability to think of themselves as "real" scientists capable of doing "real" science.

While teachers were able to plan and implement activities whereby students engaged in collecting and analyzing data, Mr. Rubin and Ms. Rossi also noted challenges students faced when trying to use data as evidence for scientific arguments and claims. For instance, Ms. Rossi shared that her "students struggled specifically with using and showcasing evidence," and as a result, "they needed extra scaffolding to included [sic] and it remained weak….I think I would help students practice with evidence (using and locating) and citing sources. I would practice identifying persuasive arguments and evidence" (Ms. Rossi, Classroom Artifact-Based Reflection #1). Ms. Rossi attributes this need to her students' lack of experience with formal scientific argumentation, and she is able to plan for what scaffolds to put in place to help her students to effectively make use of data and evidence in the future.

Mr. Rubin shared in his second written reflection that his students also experienced challenges relating to understanding and making use of scientific data and evidence, but draws different conclusions about how to support students in the future:

> I think some of the scientific aspects of my SSI were a bit challenging. The scientific evidence we researched was a stretch for some of my students, although they did understand the basic concepts of water testing of different sources. Next time, I would arrange to bring in person (or through a virtual video conference) representatives from the water department or water treatment facility, or an actual scientist that works exclusively on water testing to explain to my students the difference in drinkability of tap water vs. bottled water. (Mr. Rubin, Classroom Artifact-Based Reflection #2)

While Ms. Rossi proposes to support students in using data and evidence to support a claim by giving them more scaffolds and opportunities to practice this skill, Mr. Rubin seems less concerned about his students' ability to use data and evidence to support an argument, and instead concerned with his students' ability to comprehend the information being communicated by the evidence. For this reason, Mr. Rubin seeks to bring in a community partner (i.e., a guest speaker) to better explain the information while also increasing authenticity of the learning for his students.

PCK of Problematization

As anticipated, analysis of teacher data revealed evidence of reflexivity and dialogic conversation in teachers' PCK of problematization. In addition, I saw new themes emerge relating to how teachers focused and provided examples of manifestations of their SSIs in order to surface issues of injustice for students. These new themes are defined in this section as magnification and comparative localization.

Reflexivity

Teachers in this study showed their PCK of Problematization in part by engaging students in reflexivity. They did this by structuring learning activities in ways that built student understanding and awareness of each other and their respective backgrounds. For example, Ms. Moretti notes in her lesson plan

> With the new knowledge, the learner will be able to understand that not everyone had the same experiences within the classroom. Students will realize via the sharing out of the I Notice and I Wonder, and follow-up discussion with the exit ticket, how other students felt not having the things they would have preferred to use to design their product. (Ms. Moretti, SJSP Unit of Study)

From her lesson plan, Ms. Moretti makes it a point to focus on students' backgrounds and experiences to highlight their unique perspectives and encourage students to share them with each other. In reflecting on this and other activities Ms. Moretti led as part of her SJSP unit of study, she emphasizes the importance of safeguarding the classroom space for students, ensuring that all students can feel comfortable in expressing themselves and sharing their personal stories.

> I think a big thing with framing the activity…being sensitive enough to the students whose family – like I didn't want to make anybody feel bad because they buy fast faction because it's what families are able to afford or what's available or what they know. And also we were studying different parts of the unit. To not make people whose families may live in other countries or who's families might partake in the industry make them feel bad about what they're doing. And just being very conscious to make sure that we're not, you know, putting anyone's culture down or anyone's, you know, way of providing financially for their families. Those were the things that I was, worried about making sure that I was

> thoughtful about. That it's not judging, that we're just looking to see is it equitable. (Ms. Moretti, Reflective Interview)

Here, Ms. Moretti herself can be observed displaying reflexivity in terms of her intention to value the different cultures and countries her students are coming from, and understanding that their family ties may position them differently relative to the SSI. Similarly, Ms. Rossi discusses how trust is a central concern for her students in sharing their backgrounds and perspectives. As she puts it,

> I think a lot of them coming from certain neighborhoods in the city was stronger than, like, a specific culture, meaning there was… The background that really affected this was a background of kind of distrusting that their voice or their needs would have the heft that it needed. And then there's a, as we got into it, the first connections that a lot of the students were able to make was familial, but I don't think that was like a specific culture or like, you know, lacked in one culture and stronger than another. I think they were just reaching back to what they knew and what they could talk about more. (Ms. Rossi, Reflective Interview)

Here Ms. Rossi also points out the power dynamics felt by some of her students, noting that they did not immediately expect their voices to matter or carry as much weight as perhaps those of others would.

Further, teachers used this lens to shine a light on different tensions existing within the sociocultural context surrounding the SSI, leading to students' realizing the presence of issues of injustice inherent to the SSI. Ms. Moretti did this in her unit of study in part by having students reflect on an activity where different groups were expected to create design outfits related to Ms.

Moretti's SJSP unit of study on fast fashion and water usage, but where the different groups were purposely given uneven access to materials:

> then they had to do an exit ticket about like, how did that make you feel? When you were looking at your work, comparing it to the others, looking at the materials, like how did that make you feel to only be given a certain amount of tools to create, you know, what what you wanted in terms of clothing. (Ms. Moretti, Reflective Interview)

This type of reflection allowed students to share their thoughts and feelings related to an experience with inequity, which, while manufactured on the part of the teacher, had clear relationships to the inequities in resources seen across the globe.

On the other hand, Ms. Rossi structured opportunities for students to reveal a tension inherent in her unit of study's SSI by requiring her students to craft an argument from an opposing viewpoint:

> So, I gave them a role that was contrary to whatever their opinion was. So throughout the SSI, we would have these little vote sessions and for the practice SSI. There it was a vote session about whether students should get access to USB ports to charge their phones on buses first or not. And, they did that as their own person instead of having a role. But I would do that same kind of voting like how do you feel about this throughout? And once I knew how they felt about it, I kind of would give them a role that would push that. That thinking into a new direction. So like, you would be the, also it was like a position of leadership that they may or may not have conceived that they were able to get to. So be like a nursing home director, someone who manages a hospital. There is a bus driver on there. So it was a I would find a role that that kind of helps them find a different. A different opinion than they had. So that the first debate was kind of what themselves and

> that even if they didn't participate because of currency and other things that they would see that there's a difference between what this person was going to think and what they personally wanted to believe. In terms of saving the zoo or giving the zoo power. (Ms. Rossi, Reflective Interview)

Part of the reason for Ms. Rossi's success with this approach was that she polled the class's opinions at various points over the course of the unit of study, allowing her to better understand her students and their perspectives. This disposition toward valuing students' voices and perspectives was important for Ms. Rossi in guiding her class through further discussions in which she and her students surfaced issues of injustice related to her overarching SSI relating to societal decision-making and priorities during an energy crisis. For example, Ms. Rossi's students discussed competing needs of powering social services such as hospitals as well as different areas of their city:

> So the, the first issue [of injustice that surfaced] is who is going to be listened to by City Hall? Like who was really gonna be listen to and like was the, you know, was the debate gonna realistically only listen to the people that were really gonna be listened to? So, I think throughout the unit as kind of already just battling the fact that my students felt like they weren't gonna be listened to. And then. Then they're talking about, well, you know, people in the nursing home really can't come to City Hall, so it's not fair that City Hall is voting without listening to them and like what should happen there. Same thing with the hospitals. We talked about people. There is some discussion about people that need like the oxygen saturation machines in their house. And that it would be unfair. To not like they didn't have any warning so no one knows whether that machine is charged or not so like How are we gonna deal with that and how are we gonna make sure that that person

> could charge that machine because they needed to breathe. And then there was a lot of discussion about like. Different parts of the city and whether they were gonna get power first no matter what we said. (Ms. Rossi, Reflective Interview)

Again, the theme of trust and whose voice has the power to be listened to is embedded in the class discussion, as are themes of fairness and justice. These are important themes to consider in problematizing the issue of energy distribution in times of crisis, and the teacher was able to surface these themes organically while encouraging and structuring space for reflexivity among the students.

Dialogic Conversation

As shown in the above subsection, discussions and conversations can be helpful in surfacing issues of injustice related to an SSI. These conversations can be said to be dialogic in nature when they evolve in such a way where the participants are able to learn through conversation ideas and knowledge that neither of them possessed separately (Freire, 1970/2000). In other words, a conversation is dialogic when the whole is greater than the sum of its parts. While some of these conversations teachers facilitated with their students were structured, others seemed to arise more organically. In structuring these conversations, teachers such as Mr. Rubin would intentionally group students and have them do some pre-discussion activity based on student learning from a previous lesson, as shown in this excerpt of Mr. Rubin's lesson plan:

> Expand on earlier lessons with another reading and discuss as a class what the alternatives are to plastic bottled water. Divide the room into small groups. Give each group chart paper and have them write down advantages and disadvantages of bottled water and tap water. Discuss which one they would opt for. (Mr. Rubin, SJSP Unit of Study)

Mr. Rubin also provided structure to this activity by having students write before they engaged in oral discussion; he also had them discuss in small groups as opposed to facilitating a larger whole group discussion.

In structuring dialogic conversations in her classroom, Ms. Moretti referenced classroom norms around class discussions. Reflecting in an interview, she states:

> Those are like the classroom norms that I use for, you know, the dialogue in terms of, like, how I had the kids interact with each other. So like before they said something or made a judgment, it was like, no thank you. Before they made a judgment or something, you know, like if they were doing equitable, I could say, you know, I'd like to hear from someone who hasn't yet got a chance to talk or you know the way [another participant] described really helped me to think of it in a different way like the kids you literally would use this language because by the time they end of the year came, it had already been ingrained in them because of the way that we were like interacted in science and it just fits really nicely because if they had questions, you know, they would say, you know, I think I heard you say this. And then they'd say it again and then the person would be like, no, or yeah, that's what I said, but I didn't mean that. (Ms. Moretti, Reflective Interview)

In addition to structuring her expectations around class discussions, Ms. Moretti also provided sentence starters for her students to help them engage with each other, allowing the students to have deeper conversations and discussions than they may have otherwise had about the provided topics. Ms. Moretti also referenced external resources she drew inspiration from in structuring dialogue in her classroom:

> Honestly, one of the best ways that I was able to have like good meaningful dialogue. Was – I think it came from NGSX or NGSS –I'm not sure. I can probably look here, but it's like those, I have it on my science book – It's the Classroom norms. Classroom norms. Talk move to support, norms and this was from the [NGSS] when we did that, pilot and it's really good because it talks about like what is respectful look like what is equitable look like committed to your community and moving our science. Thinking forward. So whenever we were thinking about how we're participating interacting with anyone, we used a lot of the language from this to make sure that we are not. You know, answering in a judgment way or having, you know, like an opinion about someone's way of life, culture, custom. So I just kind of modeled the rules for dialogue just about making sure that we're, you know, being positive and thinking in a sensitive way about different people and their way of life because We truly have so many different people. From all different places. Like, you know, we're not going to say, you don't, you know, your toilets in the floor. You know? You just can't say that. (Ms. Moretti, Reflective Interview)

Ms. Moretti reflects here that, by using standardized language from respected sources (e.g., NGSS), she feels better able to protect students' abilities to engage in respectful discourse with their classmates. Interestingly, and perhaps due to her focus on norming around ways of carrying out class discussions, many of the discussions Ms. Moretti recounts appear to have emerged organically. For instance, Ms. Moretti mentions:

> I mean, we're talking about, you know, like is the water equitable. Like our waters use compared to other countries. And the students would start to say, well, we use a lot more water here because you just turn on the …in my country like we have to walk to go get it. You know, like the toilet's outside and then we started having conversations about though

> like how the toilet looks and how the toilet is used. So all of those, you know, conversations started to come together, with the students and their experiences and we had a lot of people that we're able to contribute that. (Ms. Moretti, Reflective Interview)

Here Ms. Moretti describes conversations as seeming to just come together as students share experiences. These conversations seemed to occur spuriously and spontaneously due to the way the teacher structured her class activities. For instance, also in Ms. Moretti's classroom,

> [students] had to do a, like a question poll like true or false, you know, and one of the questions, you know, was, you know, do you think, that, you know, anyone should be able to wear whatever they want and have access to all this type of stuff. That kind of created a debate because some people are like, well, no, my Muslims, you know, students were like, well, if people could wear whatever they wanted to, this wouldn't be culturally accepted for us. So kind of finding that balance of. How to, you know, be appropriate. According to like different cultures and stuff. So there was really a lot of discussion that came from that. Other people were like, no, we shouldn't be allowed to wear animals or, you know, no, we shouldn't be able to wear this because it's harmful for the environment or more harmful. So those were just some of the discussions and conversations that happened naturally. Over the 6 classes that I taught it wasn't always in one class. But since I teach all the 6 different classes, you know, they evolved over a couple of the classes. (Ms. Moretti, Reflective Interview)

While Ms. Moretti started off by doing a structured activity (i.e., a true/false poll) in this particular lesson, it quickly gave rise to an organic conversation as students sought to understand each other's cultures. While these conversations were not necessarily planned for individually, the teacher indicates through her reflections that they seemed to continue happening. This may be due to the way the teacher had initially structured her class environment in norming around discussions and discussion-based activities. These conversations also shined a spotlight on some of the injustices related to the SSI of fast fashion and water usage:

> we read about sweatshops down to like the women and they have to work the long hours and some of them have the children with them and kids are like “my aunt does that” and “that's how it is in my country” and “my mom did that.” So the interest was there because it is something that affected them. And then other students were like Wow, I didn't, I didn't think about that. I didn't realize that. I didn't know. So they were really interested in how it impacts life. And again, down to that equitable use of water. (Ms. Moretti, Reflective Interview)

Here, Ms. Moretti notes that because the examples she chose were relevant to her students, they sparked conversation and led to deeper engagement. It is important to highlight the apparent influence here between relevance, a way that teachers expressed their PCK of Authentic Activity, and facilitating dialogic conversations about the SSI, as this may provide further evidence of the overlapping and reinforcing nature of the SJSP framework. This led to Ms. Moretti’s students’ heightened interest and investment in the SSI, eventually leading them to surface injustices inherent in the SSI, problematizing it through dialogic conversation:

> In particular one of the women – the kids really wanted to find out more about her. They had a group of students that were going over and talking about fashion and stuff and like she welcomed them to her house. And again, it wasn't a judgment, but some of the students who had never experienced some of the experiences that my other students did like you walked into our house she had a bed that was on the floor. And it literally was like one room a small fridge. Not like the Bunsen burner, but it was like like a hot plate

> with like the coil thing that she would cook on and like here was her closet. And the toilet was kind of like this. She squatted over there and it was like the shower, the toilet and then like the sink was in one room. So students were really, you know, interested in finding out more. Oh my god, she works so many hours, but this is what they make. So, they were interested to figure out more about that. (Ms. Moretti, Reflective Interview)

While these issues of fairness and injustice may not have been explicitly stated by the teacher, the students were able to surface these issues through the dialogic conversations the teacher facilitated in the classroom, based on the different stimuli the teacher provided.

Magnification

Another theme that emerged in the way teachers in this study problematized issues related to their chosen SSI was through what I call magnification, which is essentially changing the scope of how the issue is focused on in class. This can be done by "zooming out," or generalizing from a particular example (e.g., asking "what would happen if everyone did xyz?") or "zooming in," or localizing a general phenomena, considering the particulars of students' geographical, cultural, and personal lives (e.g., asking "what would happen if we did that here?"). By adjusting the magnification of an issue (i.e., generalizing a particular issue or particularizing a general issue), teachers were able to draw students' attention to the various underlying tensions inherent in an SSI, thereby allowing issues of injustice to surface for students organically.

Ms. Moretti exhibited magnification through generalization by drawing on current events to provide a common point of entry for all students in the class, noting

> the students' exposure to the [city] water crisis. Equitable water access because a personal experience when people in [city] and surrounding suburbs bought the bottled

> water from within the [city]. This left many [city residents] without access to clean water. It exemplified how people bought the water in huge quanties [sic], more than needed. It also exemplified how people also took advantage of those who didn't have access to drive farther to get bottled water outside the City. They also saw the price gauging happening, where a case of water that someone could have purchased prior to the water crisis, were being sold on City street corners for $10+. (Ms. Moretti, Classroom Artifact-Based Reflection #1)

By tapping into this current event, Ms. Moretti also created a space for students to discuss how issues in their city impacted those in the surrounding areas, generalizing the issue slightly to help students view this water crisis as a part of a larger system. She reflects that, “the [city] water crisis also helped all students understand the importance of accessibility to clean water and a strong connection to better understanding how fast fashion impacts equitable access to clean water” (Ms. Moretti, Classroom Artifact-Based Reflection #1). This shows how Ms. Moretti was able to generalize the issue of a particular water crisis in a specific city to connect to the issue of access to clean drinking water on a global scale.

Similarly, Mr. Rubin also demonstrated this generalizing form of magnification, albeit in a slightly different way. While Ms. Moretti looked at current events to generalize from students' lived experiences, Mr. Rubin looked to data from student investigations, guiding them to generalize their results to larger communities. In his first reflective interview, Mr. Rubin described how

> when [the students] did their experiments using the total dissolved solids the TDS meters, they graphed their results, they explained their results, and they then filled out a lab report so that the rest of my students in the school when they're coming up to the science

> lab, even if they weren't in the classroom, they got a whole explanation about why they were doing the project that they were and the impact that is has not just on the class itself but on the entire community. (Mr. Rubin, J-STEM EOY Interview)

In going through this process, Mr. Rubin's students generalized from their own class data to their communities. From there, Mr. Rubin's students generalized further, thinking about the impacts of their SSI in other parts of the world, as Mr. Rubin notes in his first written reflection, "This was a great start and my students really enjoyed learning about the dangers of plastic water bottles, but also about why they are needed in some communities around the world due to the lack of safe drinking water" (Mr. Rubin, Classroom Artifact-Based Reflection #1). In this way, Mr. Rubin connects the data his students collected and analyzed to global issues, in addition to engaging his students in reflecting on how what they were learning could help others.

Further, Mr. Rubin also showed how he localized, or "zoomed in," with his students when having them consider watersheds and how they can be impacted by pollution. In his lesson plan, Mr. Rubin describes how

> students will learn about their watershed through a Lumio lesson, embedded with maps of creeks, rivers, the neighborhood in which they live in Philadelphia, and how plastic pollution may affect their drinking water. This Lumio presentation explores what a watershed is, how water pollution affects us, and where the watersheds are in Philadelphia. Through a series of videos from TTF, students can respond to reasons we need to keep our water sources clean. (Mr. Rubin, SJSP Unit of Study)

While water pollution is a global issue, Mr. Rubin chose to focus on how that SSI was playing out specifically in the student's geographical community. As he describes the process,

> we looked at our own watershed and we noticed that's only a 10 minute walk from our school to the Tookany Creek and we spoke about what would happen if plastic water bottles are thrown about and then they are lying in the creek. (Mr. Rubin, J-STEM EOY Interview)

In focusing on students' local communities, Mr. Rubin was able to focus student attention and guide their discussion around how ways to improve their community, culminating in an action project (discussed further in a later section).

Comparative Localization

Similar to the idea of magnification discussed above, teachers also engaged students in what I call comparative localization, a term I use to refer to the idea of changing the focus of an issue in terms of looking at different particular instances of a general or specific issue (e.g., How would things be different if we did this there? How would that be different if we did that here?), essentially "zooming in" to examine and compare how a particular SSI might, or does, play out in different contexts. One way teachers did this was by having students look at a variety of non-local contexts. For example, Ms. Moretti describes in her lesson plan an activity in which "Students use graphic organizer [linked in lesson plan] to compare impacts of fast-fashion in three different geographical places (China, Bangladesh, Indonesia)" (Ms. Moretti, SJSP Unit of Study). In this activity, students in Ms. Moretti's classroom systematically examine and reflect on the economic and environmental implications for fast fashion in three different countries.

Teachers also used comparative localization to compare and contrast impacts and nuances of SSIs between students' local context with a non-local context. Ms. Rossi, for example, engaged in this with her students in a theoretical manner, considering what could happen if an event that was actually occurring in another place were to happen in her students' city and neighborhoods instead. Ms. Rossi outlines one such activity in her lesson plan:

> Students answer the question: Could this happen in Philly?
>
> > Large Group: texas energy crisis in pa 1 and Notes
> >
> > Tables: Finish The graphic Organizer for your assigned sources in your notebook
>
> [Various articles and resources students can use:]
>
> - Texas Faces Power Outages, Freezing Temperatures During Winter Storm and One Year Later: The Texas Freeze Revealed a Fragile Energy System and Inspired Lasting Misinformation
> - Frozen Out in Texas: Blackouts and Inequity - The Rockefeller Foundation and Fact-checking the Texas energy-failure blame game - CNNPolitics
> - Frozen Out: Minorities Suffered Four times More Power Outages in Texas Blackouts - The Rockefeller Foundation and One Year Later: The Texas Freeze Revealed a Fragile Energy System and Inspired Lasting Misinformation
> - Fact check: The causes for Texas' blackout go well beyond wind turbines | Reuters and One Year Later: The Texas Freeze Revealed a Fragile Energy System and Inspired Lasting Misinformation
>
> Students look through evidence and sort into a Venn Diagram in order to help organize facts before writing a speech. (Ms. Rossi, SJSP Unit of Study)

In this activity, students are learning about an actual energy crisis that made headlines in Texas, and then are guided to think through the possibility of this happening in their own city. Ms. Rossi notes in her first written reflection that her "students showed an understanding of the electrical grid, the energy crisis that occurred in Texas and how a similar event might affect different groups in [our city]" (Ms. Rossi, Classroom Artifact-Based Reflection #1). In doing so, students were also exposed to issues of injustice related to the Texas energy crisis, such as predatory debt, as Ms. Rossi shares in her second written reflection: "Students also learned about the predatory debt that happened in Texas and transferred that concern to their neighbors and families" (Ms. Rossi, Classroom Artifact-Based Reflection #2). This shows how the teacher structured learning activities for students such that they were encouraged to transpose lessons from a nonlocal phenomenon to their local context.

When possible, teachers also sought to use comparable phenomena to compare and contrast events between their students' local context as compared to a non-local context. For example, Mr. Rubin planned activities for his students to compare the events surrounding the (at the time of this writing) ongoing water crisis in Flint, Michigan with similar concerns around the public water supply in the city his students live in:

> My students spoke about the inequities that some communities have with drinking water and how this can be addressed. We specifically looked at the challenges of Flint, Michigan and even our own water supply when [our city] had its so-called water emergency when latex chemicals were spilled into the Delaware River, causing an initial scare for people in certain parts of the city to buy bottled water. (Mr. Rubin, Classroom Artifact-Based Reflection #1)

Mr. Rubin complemented these discussions with actual student investigations in which students tested the water in their own neighborhood, as Mr. Rubin shared in his initial interview, noting "We talked about Flint, Michigan and what's going on there, and um, from the time that we even tested our own water, which we did in our unit, that's also, that has to do with social justice too" (Mr. Rubin, J-STEM EOY Interview). It is worth highlighting the connection Mr. Rubin is making between these activities and social justice, as this tracks with the notion that such comparative localization is helpful in problematizing socioscientific issues, thereby revealing issues of injustice for students to grapple with. In fact, in a later interview, Mr. Rubin acknowledges that such conversations did in fact stem from these and similar activities his students engaged in. In his own words:

> So what [my students] talked about was, well, How do some neighborhoods, particularly because we actually looked at the water situation in Flint, Michigan, what had happened there, And in some parts of even our country that there's still issues with water and old pipes– Why are some areas have better water than other areas?! And, What can we do to make it so there's clean water for everybody? That's something that was talked about a lot. And do I just because I live in the [city]? Okay. What is my water situation? Do I have clean tap? Do I not have clean tap water? And I think a lot of that has to do with perceptions. And by bringing the [city] Water Department and having them talk to my students about the purification process. I think that kind of opened up…not necessarily some debate, but about some knowledge that they might not have had before about the purification process. (Mr. Rubin, Reflective Interview)

It is also worth noting Mr. Rubin's reflection that students learned more about the STEM content underlying the SSI than they may have otherwise because Mr. Rubin presented the content through the lens of his SJSP unit of study.

PCK of Agency & Action

In analyzing teachers' PCK of Agency & Action, two themes stood out the most: the ways in which teachers prompted students to elucidate their own position or solution relative to the SSI, and the use of community improvement projects to facilitate student action surrounding issues of injustice revealed by problematization of the SSI.

Elucidate Own Position/Solution

One way that teachers exhibited their PCK of Agency & Action was the ways in which they prompted students to elucidate their own position/solution with respect to the overarching SSI in the teacher's SJSP unit of study. Some of the teachers in this study structured opportunities for students to share their opinions, positions, and/or solutions with respect to the SSI at least once while the unit of study was still "in progress" in addition to providing an opportunity for students to express their opinion, position, or solution at the conclusion of the unit of study. For example, Mr. Rubin had students elucidate their own position to the tap vs. bottled water controversy at the heart of his SJSP unit of study initially during his first lesson, as shown by his lesson plans:

> Students will watch two short videos. One is from The Story of Stuff entitled "The Story of Bottled Water" This video is pro tap water and attacks the bottled water industry. Conversely, the second video is "The Life of a Plastic Bottle" tells the story from a pro-recycling perspective from Pepsi. Students will discuss if based on watching the two vidoes [sic] should we continue to use plastic water bottles? (Mr. Rubin, SJSP Unit of Study)

Although this was just the first lesson, Mr. Rubin saw value in having his students take an initial stance toward the issue after only a surface-level introduction. Later on, in the third lesson of Mr. Rubin's SJSP unit of study, Mr. Rubin has students engage in a debate, also on the value of tap vs. bottled water:

> Students will read an article and debate if the cost alone would be worth buying bottled water. What are the alternatives? How important is bottled water to our community? What about the importance to communities outside our school area?
>
> Created Lumio is here:
>
> https://suite.smarttech.com/share/7cd16f19-0aa0-4688-817c-ff42f8c71a60
>
> Students take a position if society should ban the plastic water bottle. Show students data related to cost analysis of recycling vs. disposal on Lumio. Begin debate via graphic organizer.
>
> Students will look at cost differences between plastic water bottles and tap water. Discuss costs in analysis pros and cons to see if plastic water bottles are worth it. Discuss environmental impacts of plastic water bottles. (Mr. Rubin, SJSP Unit of Study)

From this lesson plan excerpt it can be seen that students are again asked to take a stance on the same SSI, but with the important difference that they now have been exposed to additional information about plastics and plastic water bottles vs. tap water. Similarly, Ms. Moretti gauged her students' perspective on possible resolutions to her SSI before and after leading her students in a debate about Fast Fashion, as seen in her lesson plans:

> Teacher will say "That was a great debate by everyone thank you. Are there any other points that anyone wants to discuss before we self reflect on the information we heard today"" We will now answer a reflection sheet about what you have learned, and if your opinion was changed." (Ms. Moretti, SJSP Unit of Study)

Although students likely had formed their own opinions prior to the debate, the teacher also checked in to see in what ways, if any, students' positions had changed after the debate had ended. Similar to Mr. Rubin, Ms. Moretti demonstrates her belief that there is value in eliciting student opinions multiple times over the course of an SJSP unit of study, at least in part so that students can engage in reflection on if, how, and why their opinions did or did not change. Interestingly, Ms. Moretti noted that, after the conclusion of her SJSP unit of study, students came up to her, "expressing how they were making choices to not participate in fast fashion. They also said they think differently when they go to places like 5 below and the dollar store as they were making choices to buy things 'more sustainable'" (Ms. Moretti, Classroom Artifact-Based Reflection #2). This shows the potential for SJSP for lasting influence on students' perspectives relative to an SSI. Interested in more than just a perspective shift, some teachers such as Ms. Rossi expressed the intention to have students thinking beyond just a class assignment, empowering them to contribute to meaningful resolution of an SSI. In thinking about what she would do differently in the future, Ms. Rossi shared the following reflection:

> I think if I could do it again that that idea of like, OK so we've passed this policy, you know, what do we have to think about or what do we have to worry about or what can we actually fix right now to kind of bring in this idea of of of looking at those specific groups and thinking about those specific groups, in terms of a system that isn't ever going to be perfect, you know, but how do we head there or how do my students head there without, without considering it fixed just because we had the town hall meeting. (Ms. Rossi, J-STEM EOY Interview)

This suggests a need for teachers to go beyond having students simply elucidate their own position or solution to resolve an SSI, but to actually take some action to help resolve the SSI.

Community Improvement Projects

As suggested by Ms. Rossi's reflection in the previous subsection, teachers saw a need for students to engage in actions to help in resolving the SSI central to the SJSP unit of study and to improve their communities. While these community improvement projects may involve community partners as described in the previous section, PCK of Authentic Activity, this is not the defining feature of a community improvement project. Rather, these are any projects in which students are engaged in some action where they are directly seeking to improve some aspect of their community, whether that means their school-community, neighborhood-community, or any other community they identify, in some way pertaining to the SSI at the heart of the SJSP unit of study. For instance, Ms. Moretti describes how her students

> wanted to hold a school wide collection of clothing and send them to places to be recycled, upcycled, or down cycled, they wanted to write to local representatives to get more recycling drop locations. They wanted to make posters and put them around the community to make people aware of clothing in landfills and the hazards of fast fashion. (Ms. Moretti, Classroom Artifact-Based Reflection #2)

This would be considered a community improvement project that sought to improve the students' school-community, and it is related to Ms. Moretti's SSI (Fast Fashion). Ms. Moretti described her plan for this community improvement project in our first interview, stating

> We're gonna do a school-wide collection there's a place I found on one of the articles. And I think it was [J-STEM Facilitator], but somebody had said sent me to an article, and they were like, Oh, there's this place that recycles clothes. They upcycle, downcycle, or recycle them So we're gonna have a schoolwide collection to be able to collect the clothes and it's other stuff, too, like they don't just do clothing. So we're gonna try to collect as

> much as they can and then they come to the school and then they pick it up. Yeah. So we've moved and other teachers are getting involved because, like the math department, they're going to be calculating how much it weighs in doing all the mathematic calculations for that and you know, So we're gonna be like blending The science and the math, and it's not just like – It's my whole team now versus just one getting involved in doing that. (Ms. Moretti, J-STEM EOY Interview)

In carrying out this community action project to benefit the students' school-community, Ms. Moretti also sought to involve other teachers at the school, as well as a community partner to facilitate the recycling initiative. This speaks to the importance of teachers being able to coordinate with other individuals and groups in planning such projects. Unfortunately, this ended up proving to be a barrier to accomplishing the project when Ms. Moretti could not work out with others at the school where the clothes to be collected for the recycling drive would be stored, as she described in her follow-up interview:

> So we did [have a culminating activity], the first year start. To contact the place We were, working with the math, teacher that works with the sections that I taught. And we were trying to like collect as many bags of clothes as we could to like calculate how many you know tons or pounds of clothes we were keeping out of the landfill, but that wasn't able to come to fruition, because of other things that. School had going on. So That's what it was supposed to be the culminating activity. (Ms. Moretti, Reflective Interview)

Although Ms. Moretti could not implement her preferred culminating SJSP activity with her students, her intention to do so still shows the value she places on community improvement projects. Despite not being able to implement the project in its entirety, Ms. Moretti notes that students still engaged in the intellectual work of planning out the clothes drive:

> But the students had started to plan. You know, the clothes selection and it just never came to fruition. And what, so what got in the way of the, the clothes collection plan. Space to house the clothes. Nobody wanted to give up any space to be able to house them. And we were told at first we'd be able to use our back loading dock and then our person was like no because every person that says that they're gonna put something back there and take it away. It never happens. So there was an actual space issue in terms of collecting. (Ms. Moretti, Reflective Interview)

While unfortunate, Ms. Moretti's attempts at engaging students in community improvement projects speak to both the value of such projects as well as the support needed to actually carry them out. In particular, it speaks to the importance of negotiating multiple perspectives around what Ms. Moretti describes the issue of different individuals supporting the idea of the community improvement project, but for various reasons not wanting to commit their own resources. This tension Ms. Moretti describes here points to potential pitfalls in organizing community improvement projects.

Mr. Rubin, on the other hand, had more luck with his planned community improvement project, which was more centered on the students' neighborhood community. Similar to Ms. Moretti, Mr. Rubin also sought to work with community partners to help facilitate community improvement projects for his students. In an interview, he shared that

> I partnered with a organization called the Tacony Creek watershed foundation. And what they did was they came in and did a lesson with my students – a hands on lesson about the effect of pollution plants, specifically plastic water bottle pollution. And where that plastic water bottle really ends up. And to make them the agents of change, my students, we actually got them to go out in the neighborhood with decals to put on storm drains

> saying that this water drains to the local river, please do not pollute. And we understood where our watershed was and what effect that it would have. On our water supply and our drinking water. They're really interested in that and to know that the watershed literally the creek is Like about a 10 min walk from the school. (Mr. Rubin, Reflective Interview)

For Mr. Rubin, this community improvement project was a meaningful culminating activity for students because it allowed students to make a change within their community related to the scientific content they learned in his class. Mr. Rubin also notes the engagement students experienced through this community improvement project, and, later on in the interview, he talks about his intention to build on this success to launch a recycling program in his school in continued efforts to extend learning beyond the walls of the classroom:

> Actually having my students going into the neighborhood to put down decals on storm drains about the… this water drains to our local river. It really lets my students become the agents of change outside the classroom. And now it's moving into the community. Now my students are making an impact hopefully in the community by doing this. But what I said before was what I really need to do is to launch a recycling program in the school level and possibly even bring that in some way to the local community. And to make other people aware of the dangers of plastic getting into our waterways and what harm it can cause. So that moves it beyond the classroom. (Mr. Rubin, Reflective Interview)

Mr. Rubin is clear here that having his students participate in this community improvement project was essential not just in furthering their learning of the content, but also in empowering students to make a positive change in their community based on the SJSP unit of study he had developed.

Similarities and Differences Between Participants' PCK

In addition to describing the ways in which teachers exhibited their PCK across the domains of SJSP, it is worth highlighting some of the similarities and differences between the PCK expressed by the different teachers in this study. Table 3, below, summarizes these similarities and differences in terms of which PCK was and was not expressed by each participant. For instance, while all participants exhibited PCK of Authentic Activity in terms of utilizing student voice and emphasizing the need to make learning relevant to teachers, they differed in their expression of PCK relating to their involvement of community partners. While Mr. Rubin and Ms. Moretti both incorporated community partners, Mr. Rubin did so in a way that emphasized STEM content, whereas Ms. Moretti made use of community partners to deepen students' understanding of the sociocultural context surrounding the SSI at the center of her unit of study. Ms. Rossi, on the other hand, did not involve community partners in her SJSP unit of study, but did express an intention to do so in her second artifact-based reflection. Additionally, while all participants exhibited PCK of Sociocultural Context in terms of their use of socioscientific issues and multiple perspectives, the remaining domains of PCK of SJSP revealed some important differences. Within teachers' PCK of STEM content, only Mr. Rubin and Ms. Rossi showed evidence of this PCK in terms of STEM modeling and Data Collection & Analysis, while Ms. Moretti did not definitively express this PCK in ways captured by this study. However, Ms. Moretti did express her PCK of Problematization in terms of reflexivity, dialogic conversation, magnification, and comparative localization, whereas Ms. Rossi and Mr. Rubin only exhibited certain of these themes within their PCK: Mr. Rubin did not exhibit reflexivity, and Ms. Rossi exhibited only reflexivity and comparative localization. Finally, in terms of participants' PCK of Agency & Action, while they all expressed this PCK in terms of having students elucidate their own position/solution and through the use of community improvement projects, they had different levels of success regarding these projects. While Mr. Rubin successfully developed and implemented a community improvement project with his students, Ms. Moretti planned a project but was not able to implement it due to barriers relating to her school context. Ms. Rossi did not develop or implement such a project, but did express an intention to do so, speaking to her awareness of this component and showing that she values it as well.

Table 3

Similarities and differences among participants' PCK of SJSP

	Mr. Rubin	Ms. Rossi	Ms. Moretti
PCK of Authentic Activity			
Student Voice	x	x	x
Relevance	x	x	x
Community Partners	x (STEM Content)	i	x (Sociocultural Context)
PCK of Sociocultural Context			
Socioscientific Issues	x	x	x
Multiple Perspectives	x	x	x
PCK of STEM Content			
STEM Modeling	x	x	
Data Collection & Analysis	x	x	

	Mr. Rubin	Ms. Rossi	Ms. Moretti
PCK of Problemation			
Reflexivity		x	x
Dialogic Conversation	x		x
Magnification	x		x
Comparative Localization	x	x	x
PCK of Agency & Action			
Elucidate own position/ solution	x	x	x
Community Improvement Project	x	i	a

Note. x = expression, i = intention, a = attempted

Chapter 5: Summary and Discussion

Reforms in Science, Technology, Engineering, and Mathematics education over the past several decades have resulted in a somewhat steady pressure to infuse it with personal, social, and cultural relevance (DeBoer, 1991; Gallagher, 1971; Hekimoglu & Sloan, 2005; ITEEA, 1996, 2020; NCTM, 2000; NRC, 1989, 2009, 2010, 2012). This emphasis on relevance eventually resulted in a push for social justice in education as a means to both engage learners and to develop students' moral and ethical reasoning abilities in hopes that this would lead to a more just world (Dos Santos, 2009; Zeidler, 2016). Amidst rising concerns for relevant and equitable curricula, SSI can be seen as an avenue to provide STEM teaching through a more justice-centered approach (Dos Santos, 2009; Morales-Doyle, 2017). However, engaging in social justice pedagogies in general is not always easy for teachers and is often underexplored for STEM teachers in particular (Kokka, 2018). For instance, teachers often struggle with implementing SSI due to issues with time constraints, confidence, and support (Fadzil, 2017; Saunders & Rennie, 2013).

This study used a case study design (Creswell & Poth, 2018; Yin, 2018) to explore the ways teachers in the J-STEM program develop and conceptualize their Pedagogical Content Knowledge (PCK) relating to Social Justice STEM Pedagogy (SJSP). Specifically, this study explored the ways in which teachers participating in the J-STEM program developed and refined their pedagogical content knowledge of SJSP throughout the course of the program, guided by the following research questions:

1. RQ1: To what extent did teachers adapt their PCK of SJSP in the (re)development of a unit of study?

2. RQ2: To what extent did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom?
3. RQ3: To what extent were teachers' PCK of SJSP similar and different as they (re)developed a unit of study?

In this case, all of the research questions are focused on the PCK of SJSP for teachers participating in the J-STEM program. Therefore, the case under investigation is identified as the development of secondary teachers' PCK of SJSP in the context of the J-STEM program. This constitutes what Creswell and Poth (2018) refer to as an intrinsic case, as it "presents an unusual or unique situation" (p. 99) where teachers of STEM subjects are engaging in structured professional learning centered around infusing social justice into STEM. Bounding the case is important in deciding how to focus the case, such that there is clarity between what constitutes the case and what constitutes the context thereof. This case was bounded to the experiences and perceptions of teachers in the inaugural cohort that relate to the development of their PCK of SJSP. Other participants, staff, program activities, etc. are seen as the context within which the case resides. Three of these teachers were enrolled as participants in this study. As mentioned in chapter 3r, all three are white, veteran teachers with more than 10 years of teaching experience teaching in public schools in low-income neighborhoods. Mr. Rubin is male, while Ms. Rossi and Ms. Moretti are female. Ms. Moretti and Mr. Rubin taught 6th grade science, while Ms. Rossi taught 11th and 12th grade physics and chemistry. None of these teachers had experience teaching with SSI prior to joining the J-STEM program.

As mentioned in chapter 4, this study explored the PCK of three in-service science teachers as expressed through the development, and redevelopment, of a unit of study aligned to the SJSP framework. The SJSP framework includes 5 domains: Authentic Activity, Sociocultural

Context, STEM Content, Problematization, and Agency & Action. The first research question answered by this study was the extent to which teachers adapted their PCK of SJSP in the (re)development of a unit of study. Teachers in this study expressed PCK of Authentic Activity throughout their SJSP unit of study, showing that they sought to make learning authentic while they incorporated each of the additional four SJSP domains consecutively. Teachers did this by incorporating and valuing student voice, making learning relevant to their students, and engaging community partners throughout their units of study. Two teachers in this study began their unit by introducing the sociocultural context and then digging deeper to uncover the STEM content underlying it, while the third teacher started with the STEM content and proceeded to layer the sociocultural context on top. Regardless of the order they chose in moving through the framework, the teachers expressed their PCK of Sociocultural Context by engaging students in exploring socioscientific issues and analyzing these issues through multiple perspectives, and expressed their PCK of STEM Content through their use of modeling and through the ways in which they had students collect and analyze data. After guiding their students through the STEM Content and Sociocultural Context relevant to the SJSP unit of study, teachers engaged students in problematizing the underlying SSI. Teachers in this study expressed their PCK of Problematization in a variety of ways, including engaging students in reflecting on the relationship between the perspectives people have based on their backgrounds and experiences (reflexivity) and engaging in meaningful dialogue around these varied perspectives and implications relative to the SSI (dialogic conversation). Teachers further expressed their PCK of Problematization in the way they illuminated tensions inherent in the SSI central to their SJSP unit of study by asking students to consider how implications of the SSI and potential resolutions thereof would play out on a local vs. a global scale (magnification), and furthermore how the particulars of the SSI shifted depending on the locale the SSI was applied to (comparative localization).

Finally, teachers built on students' capacity to problematize the SSI, surfacing issues of injustice, to cultivate students' Agency and support them in Action related to resolving the SSI. Data collected relating to this domain helped to answer the second research question of this study: To what extent did teachers use their PCK of Agency & Action to extend learning for students beyond the walls of the classroom? Teachers expressed this PCK of Agency & Action through the ways they had students elucidate their own positions and solutions with respect to the SSI and by engaging students in community improvement projects. In extending student learning beyond the walls of the classroom, teachers seemed to primarily emphasize the importance of community improvement projects. For example, Ms. Rossi expressed her intention of wanting to do such a project with students, Ms. Moretti attempted to do such a project, and Mr. Rubin succeeded in doing a community improvement project with students.

The third and final research question answered by this study was: To what extent were teachers' PCK of SJSP similar and different as they (re)developed a unit of study? Teachers' PCK of SJSP differed in the ways in which they emphasized different domains. For example, Mr. Rubin focused on ways to incorporate more community partners into his unit (Authentic Activity). Ms. Rossi focused on encouraging student voice (Authentic Activity). Ms. Moretti focused on structuring discussions to draw on her students' experiences (dialogic conversation and reflexivity: Problematization). Additionally, as mentioned earlier, participants differed in the way they organized the SJSP domains within their unit of study. While Mr. Rubin and Ms. Moretti began with introducing the SSI, thereby setting the Sociocultural Context for the unit of study, Ms. Rossi chose to begin with the STEM Content of electricity. Additionally, teachers emphasized the STEM Content differently within their units of study, with Ms. Rossi and Mr. Rubin leading students in more investigations where they were expected to collect and analyze their own experimental data.

In the remainder of this chapter, I will discuss the findings detailed in chapter 4 in terms of their connection to previous research and existing theory and the J-STEM professional development (PD) program detailed in chapter 3, as well as the implications of this study's findings along with recommendations for future research in light of current research and the limitations of this study.

Discussion and Conclusions

The findings of this study are important because they provide a glimpse of a potential roadmap for teaching STEM for social justice in ways that engage learners in complex, analytical thinking, allow for students to bring their whole selves into the classroom in order to make sense of topical issues facing them and their communities, empower and support students in improving conditions and solving social problems within their own communities, grounded in a sense of scientific understanding, and facilitate student problematization of issues related to the organizing SSI within an SJSP unit of study. While these ideas are often talked about, to the point of idealization, many educators nationwide still struggle to realize ways of teaching STEM in ways that are more relevant, rigorous, and impactful for students (Fadzil, 2017; Saunders & Rennie, 2013). In particular, teacher preparation programs and professional development programs that are able to offer insights needed to prepare teachers to teach in these types of ways are scarce and often inaccessible to many of our nation's teachers (Basile & Azevedo, 2022; Friedrichsen & Berry, 2015). Even the J-STEM program is, in many ways, a one of a kind professional development opportunity for teachers in this respect, hence its suitability as an "intrinsic case" (Creswell & Poth, 2018) for this study.

One of the additions this study brings to theoretical understandings of what a social justice STEM pedagogy might look like is its attention to helping students navigate and understand STEM content through collecting and analyzing data. This is especially important given that a common criticism of social justice teaching orientations is that they are often said to lack disciplinary rigor (Cochran-Smith et al., 2009; Morales-Doyle, 2015). Similarly, despite the consistent push within STEM education toward making curricula and classroom learning more relevant to students, many educators have struggled with this endeavor, both in actual practice and in conceptualizing how to begin said practice (Holbrook & Rannikmae, 2009; Mohr-Schroeder et al., 2020). As such, social justice STEM educators can benefit from direction and examples in this area. In the following subsections, I will draw on my research findings and delve deeper into the themes and implications in the context of current research in the areas of teachers' PCK of Authentic Activity, Sociocultural Context, STEM Content, Problematization, and Agency & Action.

PCK of Authentic Activity

Authentic activity is a central component of the SJSP framework I outlined in chapter 2, as ideas and impressions of authenticity permeate into the peripheral components of Sociocultural Context, STEM Content, Problematization, and Agency & Action. Teachers in my study exhibited PCK in this central component by incorporating and valuing student voices, working to make learning activities relevant to the lives of students in their classrooms, and connecting with community partners to add a level of realism to the learning in which students engaged over the course of teachers' SJSP units of study.

Student Voice

Findings within this study suggest that teachers valued and incorporated student voice in ways that made learning more authentic to their students. For example, Ms. Rossi valued student voices by providing opportunities for them to express their thoughts and feelings related to the SSIs at various points throughout her lesson. Ms. Rossi's ability to leverage student voices may have emanated in part from her desire to encourage students to take ownership over some of the class discussions. Her willingness in "letting my students have a stronger voice and not letting my preconceived notions and possible misconceptions dictate which way this [conversation] goes" (Ms. Rossi, Reflective Interview) adds authenticity to student learning through the teachers' emphasis on speaking *with,* as opposed to *for*, students (Fielding, 2004). Moreover, it is interesting to note the parallels in Ms. Rossi's decision to value student voice in designing and adapting her unit of study and the J-STEM program's emphasis on participant voice throughout the two year PD. J-STEM researchers collaborated with external evaluators to solicit participants' opinions at multiple points throughout the program's duration, using participant feedback to adjust the PD workshops and coaching support provided as well as to revise the unit of study template J-STEM teachers used to design their SJSP units of study.

While findings in this study implicate student voice as a way of adding authenticity to class activities through providing opportunities for students to voice their opinions and engage more with lessons, student voice has been conceptualized in the research base as relating to school governance in terms of student capacity for decision-making and input regarding school policies (Bartousis et al., 2016; Fielding, 2004). Bartousis et al. (2016) analyzed interview data from staff and young people at a community college in Australia for emergent themes pertaining to student voice, and their findings provided evidence of student voice in terms of students' influence on school-level curricular choices based on student interests and strengths. Although findings from Bartousis et al. focus more on student voice at the school level, findings from this study showed evidence of teacher consideration of student voice at the instructional level. These findings are complementary in that they both reveal ways that educators value student voice in terms of the interests and opinions voiced by students, and use them to provide more relevant educational experiences for students. This theme of relevance will be discussed further in the following subsection.

Relevance to Students

In addition to valuing student voices, findings from this study also suggest the importance of relevance in enhancing the authenticity of teachers' SJSP units of study. Morales-Doyle (2015) presents a complementary extended case study of various justice-centered units of study within a high school chemistry course that emphasized relevance to students in ways similar to teachers in this study. For example, Morales-Doyle engaged students in a soil project that was relevant to students' lives by building the unit around a relevant SSI, the presence of a coal power plant in students' neighborhood, through which students learned about chemical reactions, a process he described as a problem-posing approach to relevance. This is similar to the way Mr. Rubin designed his SJSP unit of study, in which Mr. Rubin chose an SSI related to plastic water bottles specifically because he noticed the majority of his students used plastic water bottles on a daily basis, bringing them into the classroom with their other belongings. In contrast, Ms. Rossi began her SJSP unit of study focusing on energy crises with lessons around electricity, but made this content relevant to students by connecting it to students' attachment to their cell-phones, which depend on electricity. While Ms. Rossi's SJSP unit of study had a different starting point than that of Mr. Rubin, both teachers' units were driven by an organizing SSI, and as such they both fall under Morales-Doyle's problem-posing qualification. Another example of relevance Morales-Doyle found that was not definitively seen in this study was what he described as injected relevance, as seen in how he designed units of study around stoichiometry and chemical equilibrium by "injecting relevance" into standard chemistry topics by adding real-world examples such as fossil fuel dependence and alternative energy. This differs from findings from my study in that my participants' SJSP units of study were all guided by an organizing SSI as opposed to being driven primarily by content. Although at first glance Ms. Rossi's unit of study may appear to be more in line with injected relevance than problem-posing, her unit of study shows students moving through lessons building toward the resolution of her organizing SSI, responding thoughtfully to hypothetical calls to prioritize saving the zoo in the event of a city-wide energy crisis.

It is also important to note that teachers' success in enhancing the authenticity of their SJSP units of study through making learning relevant to students' lives suggests that teachers were attentive to and knowledgeable of their students' needs, interests, and motivations, an important aspect of PCK (Magnusson et al., 1999). While the J-STEM PD could not realistically foresee SSI that would be relevant to all the students of all the teachers in the program, J-STEM facilitators did emphasize the importance of being attentive to one's students in order to select a relevant SSI around which to organize the SJSP unit of study. For example, in one of the first workshops, teachers were presented with over 15 potential SSI topics that may be interesting to students, and to think through what their students might find most relevant. J-STEM facilitators also suggested polling student opinion on SSIs the teacher was considering using to help gauge relevance and promote the authenticity of the SJSP unit of study.

Community Partners

A final theme within PCK of Authentic Activity that emerged from this study revolved around the use of community partners in planning authentic learning activities within teachers' SJSP units of study. Ms. Moretti hosted a guest speaker in her classroom to discuss her experiences relating to growing up and living in a different country where she had to gather water for her family. The involvement of this community partner enhanced the authenticity of Ms. Moretti's SJSP unit of study around water usage and fast fashion by allowing her students to hear first-hand accounts relating to issues of injustice inherent in the SSI (i.e., inequitable access to clean drinking water exacerbated by the fast fashion industry); Ms. Moretti indicated that this resonated with many of her students because they had family members with similar experiences who lived in other countries. This finding shares some similarities to the study by Casper and Balgopal (2020) exploring the influence of guest speakers based on student learning in the context of an undergraduate course on socioscientific issues relating to environmental issues. Based on student interview data, Casper and Balgopal found that guest speakers students viewed as memorable and influential to their learning presented emotionally-charged stories that foregrounded specific cases or experiences before connecting to abstract concepts or theory, and made their presentations interactive. While the guest speakers in Casper and Balgopal's study represented a range of stakeholders, such as lawyers, county planners, and geologists, the guest speaker in Ms. Moretti's unit of study was an author and activist. This is worth noting given that authors like Ms. Moretti's guest speaker may have the capacity for storytelling in ways similar to Casper and Balgopal's characterizations of their influential speakers, although the degree to which Ms. Moretti's guest speaker's presentation was interactive is unclear.

In addition to involving guest speakers in SJSP units of study, Mr. Rubin brought in community partners from a local environmental organization. These community partners also added authenticity into Mr. Rubin's SJSP unit of study by coming into Mr. Rubin's classroom to engage students in workshops around microplastics in water and their impact on living things. Following Casper and Balgopal's (2020) study, the interactive nature of the workshops facilitated by Mr. Rubin's community partners may have made the activities and learning more memorable and influential for Mr. Rubin's students, thus adding authenticity to his SJSP unit of study.

Similar to Mr. Rubin and Ms. Moretti, the J-STEM program also made use of community partners in the professional development workshops offered to teachers. For example, J-STEM brought in multiple guest speakers, including a university professor who spoke about her work with securing living accommodations for families experiencing homelessness and a prominent scholar who quite literally wrote the (practitioner friendly) book on SSI. Both of these speakers told personal stories (similar to Ms. Moretti), and one engaged teachers in a workshop (similar to Mr. Rubin) showcasing SSI-related teaching strategies like the argument line (Kahn, 2019) to structure debates. This may indicate an influence of the J-STEM program on teachers' PCK of Authentic activity as it relates to involving community partners.

As Authentic Activity is at the core of SJSP, it is worth pointing out where it overlaps with the other SJSP domains. For example, in making activities more authentic through relevance to students, much of this relevance came from the sociocultural context teachers selected for their organizing SSI. The added authenticity from utilizing student voice also played a role in engaging students in dialogic conversations to problematize the SSI and in empowering students to elucidate their own position or solution with respect to the SSI, a component of Agency & Action. Furthermore, teachers made use of community partners to add authenticity both to STEM content, as with Mr. Rubin's community partners who facilitated microplastic workshops with students, and to the sociocultural context, as with Ms. Moretti's guest speaker who shared personal stories related to the SSI. While these overlaps may suggest an interdependent and self-reinforcing nature of SJSP, it is also worth looking at findings from each SJSP domain separately in order to highlight some of the more distinctive features of PCK of SJSP, as I do in the subsequent subsections.

PCK of Sociocultural Context

Embedding STEM content within a sociocultural context is an important part of SJSP, as it can make the content more engaging and meaningful for students (Ewing & Sadler, 2020), as well as provide a natural entry point into complex cases for students to practice integrated problem-solving, a major focus within STEM education (Holbrook & Rannikmae, 2017; Owens & Sadler, 2020). Findings from this study emphasized two themes in teachers' PCK of Sociocultural Context: the ways in which they integrated SSIs into their SJSP units of study, and the ways in which their units of study invited students to consider multiple perspectives.

Socioscientific Issues

Findings from this study suggest that teachers organized their SJSP units of study around socioscientific issues to provide a sociocultural context for the STEM content. Ms. Rossi, in her SJSP unit of study, contextualized science content related to energy and electric circuits within the context of a large-scale energy crisis. This contextualization, she reported, allowed her to better engage her students based on the way it added relevance by connecting to the students' interests in their ability to charge their phones. Moreover, Ms. Rossi capitalized on this heightened engagement with students by coming back to this SSI throughout the lesson, using it as a focal issue. It is worth highlighting Ms. Rossi's success in this area, as the use of SSI as a focal issue within a unit of study is not always easy for teachers (Bossér et al., 2015; Deniz & Adibelli, 2015). For example, when Deniz and Adibelli (2015) used interviews, questionnaires, and video-taped classroom observations to explored the PCK of 2nd grade teachers who had taken a graduate level course on science teaching methods, they saw teachers engage students in scientific phenomena based on real-world contexts, such as the movement of windmills, and considered students' backgrounds in selecting and modifying STEM activities. However, this context and attention to student backgrounds were used primarily in service to further the understanding of scientific enterprise, as opposed to how scientific understandings impact the resolution of important societal issues relevant to students. Teachers in Deniz and Adibelli's study emphasized different aspects and practices aligned with STEM content, such as supporting claims with evidence and sensemaking, which, while important, puts the sociocultural context on the periphery of the lesson. This distinction, while subtle, shows the difference in value and purpose Ms. Rossi placed on her SSI as having a central role in her unit of study as opposed to a simple aside used briefly to illustrate a finer point of a scientific principle.

This difference in application of sociocultural contexts through SSI could be related to Ms. Rossi's participation in the J-STEM program, which explicitly discussed the use of SSI as organizing themes for teachers' units of study. Within the J-STEM program, teachers explored video clips and news articles that elaborated on a particular SSI and engaged in discussions centered on unpacking the various systems related to the SSI that were associated both with STEM content and sociocultural contexts. Findings from this study indicate that Ms. Moretti and Mr. Rubin placed similar emphasis on their SSIs, using them as an organizing construct in their SJSP units of study. For example, Mr. Rubin had students examine videos and articles to better understand the context behind the plastic water bottle SSI, similar to the strategies teachers engaged in during the PD. As such, there may be a link between teachers' PCK as expressed through their SJSP units of study and their experience as participants in SJSP learning activities throughout the J-STEM program.

In organizing their SJSP units of study, one of the ways teachers in this study kept the SSI at the center was by engaging students in exploring and unpacking multiple stakeholder perspectives, which I discuss in the following subsection.

Multiple Perspectives

Findings from this study indicate that, in organizing their SJSP units of study around authentic SSI, teachers in this study were also able to dig into the nuance of the SSI by engaging students in considering multiple perspectives, which may have led to deeper learning for students. In Ms. Rossi's class, students considered multiple perspectives by participating in an activity where they role-played as different stakeholders (e.g., hotel director, police officer, tax-payer with three children), arguing a position relative to the SSI based on their assigned stakeholder perspective. Afterwards, Ms. Rossi reflected that through the act of analyzing the SSI from multiple viewpoints, students ended up changing their initial stance on an SSI. This suggests that this perspective-taking activity was a powerful way of persuading students to be more open-minded in considering how a single issue can impact multiple people in a variety of ways based on how they are connected to the SSI. This use of perspective-taking is a significant contrast from Bossér et al. (2015), who explored the challenges faced by two high school teachers in incorporating SSI into a social studies course offered at a public high school in Sweden. Despite the teachers in Bossér et al.'s study having previously taking a graduate course on SSI, the teachers frequently expressed their inability to engage students in discussions, to the point that only a handful of students shared even their own perspective, and teachers did not attempt to engage students in activities that required or encouraged students to consider the perspectives of others. Bossér et al. attributed this to the teachers' mindsets and beliefs about both the teachers' perceived need to strengthen students' understanding of fundamental science concepts, and teachers' belief that the students' backgrounds and experiences were either nonexistent or irrelevant to the science content they were trying to teach. On the other hand, and as discussed earlier, teachers in this study saw value in students' backgrounds, perspectives and voices, using them as reason to select the very SSI used to organize the unit of study. These differences relate to the teachers' PCK in that teachers' orientations toward teaching impact the way they conceptualize everything from instructional strategies to what they feel is important to understand about students (Lee, 2016; Magnusson et al., 1999).

However, teachers' beliefs and intentions alone are not enough to successfully develop and implement SJSP units of study; PCK relating to instructional strategies and how to use them in service of SJSP is likewise important. The J-STEM program was intentional about preparing teachers specifically to incorporate perspective-taking into the SJSP units of study the teachers developed as part of this program. This emphasis on perspective taking was positioned by Sadler et al. (2007) as being an important component in the reasoning abilities students need to successfully resolve SSIs. Sadler et al. saw evidence of this finding through their study based on interviews of 24 6th-grade students who had recently completed a 10-day unit of study focusing on an SSI related to water quality. While Sadler et al.'s study focused on students, my study examined the PCK teachers' need to design instruction that facilitates this type of moral and ethical reasoning. Findings from this study suggest that this effort was successful, as the study participants were able to engage students in exploring multiple stakeholder perspectives relative to the SSI that organized their SJSP unit of study. For example, Ms. Rossi engaged students in an activity where they role-played different stakeholder perspectives, including healthcare workers, police officers, and real estate agents. This activity, she said, was helpful in deepening students' understanding of the complexities surrounding her SSI, as it forced them to think through perspectives that sometimes conflicted with their own. Equally important to note are the similarities between Ms. Rossi's activity and an activity from the J-STEM Fall Institute where participants engaged in a perspective-taking roleplay as various stakeholders concerned with SSI of lowering speed limits. This suggests that the J-STEM PD experience was influential in the development of Ms. Rossi's PCK of Sociocultural Context.

Teachers' PCK of Sociocultural Context is important for situating the STEM Content in which they engage learners through their SJSP units of study. The PCK of STEM Content illuminated through this study is discussed further in the following section.

PCK of STEM Content

Ensuring the thoughtful teaching of STEM Content is of major importance in SJSP. Findings from this study showed how teachers focused on academic STEM content through the use of STEM Modeling and the ways in which they leveraged students' collection and analysis of data.

STEM Modeling

The practice of STEM modeling involves developing, using, critiquing and adjusting STEM models, which are explicit representations of students' understanding of a phenomenon. These representations can be conceptual, mathematical, physical, or computer-based models (Macalalag, 2012). Teachers in this study made use of the practice of STEM Modeling to help build students' understandings of the scientific phenomena underlying the SSI at the heart of teachers' units of study. For instance, Ms. Rossi began her SJSP unit of study by engaging students in a modeling activity around electricity using energy balls, which she notes helped her students to extend their initial understanding of electricity. To help students revise and extend their understanding of the STEM content embedded within her SJSP unit of study over time, Ms. Rossi, in a later lesson, gave students the choice of using physical or computer-based models to investigate how to "break" an electric circuit. The purpose Ms. Rossi gave her students in this activity was well suited to the organizing SSI of her unit of study, given that it was centered around priorities during a mass power outage. This finding highlights the importance of teachers' PCK blending content with context in developing SJSP units of study. The capacity of teachers to blend STEM content with a sociocultural context was also observed in a previous case study (Minken et al., 2021) following 11 pre-service and 18 in-service teachers, the majority of which were taught STEM subjects in grades 6-12, who attended three intensive workshops on SSI teaching methods over the course of five months. Over this period of time, the teachers worked collaboratively in heterogeneous groupings with respect to pre-service/in-service status and subject area in order to develop and implement an SSI lesson plan (Minken et al., 2021). Findings from Minken et al. (2021) indicated that teachers showed increased sophistication in social and scientific components within their lesson plans, although teachers seemed to give more attention to detailing the social components of their lesson plans. In particular, Minken et al. saw an overall increase in teachers' PCK of STEM Modeling, and these modeling examples were situated within a sociocultural context, such as with one teacher who used modeling with neighborhood data on arable land to have students predict their neighborhood's crop potential. This shows similarities in teachers' PCK of STEM content in how teachers used the practice of STEM modeling with their students in ways that effectively situated the content within a sociocultural context. A somewhat contrasting example comes from the study by Guzey et al.

(2020), which helped teachers in grades 4–8 by providing professional development sessions geared toward integrated STEM through engineering in which teachers created practical prototypes of potential relevance to students, such as windmills that generated electricity, artificial dialysis machines, and rainwater collection systems meant to benefit those without stable access to potable water. However, teachers in Guzey et al.'s study did engage in STEM modeling, specifically in developing and revising models. Teachers focused primarily on the integration of engineering into existing math and science curricula without explicit focus on resolving SSIs and issues of injustice, whereas such attention to social justice and SSI was a specific goal for teachers in the J-STEM program.

Within the J-STEM PD, teachers were also shown the importance of STEM modeling through engaging in several workshops and learning activities involving this practice. For instance, in the speed limit activity, teachers designed, tested, and revised physical models of car bumpers that could be used to keep a person, represented with an egg, safe in the event of a collision. Similar to findings from teachers in this study, this use of modeling was related to the overarching SSI involving changing speed limits, as one of the social considerations that emerged from this SSI was safety and car crashes. In fact, teachers were also able to engage with an interactive map showing locations and outcomes of car crashes around the city. This shows how J-STEM teachers learned about STEM modeling in ways that related to the organizing SSI for an SJSP unit of study, which may suggest that the PD was helpful in the blending of STEM content and sociocultural context seen in the findings of this study.

Data Collection and Analysis

Findings from this study support the idea that collecting and making sense of data is an important aspect of SJSP. Mr. Rubin, for instance, dedicated time in his SJSP unit of study to facilitate student collection and analysis of water quality data using local water samples as well as having his students analyze water quality data collected by the EPA. Not only did Mr. Rubin value the practice of engaging his students in collecting and analyzing data, he also made sure that the data students engaged with was relevant to his SSI. Water quality data was important for resolving Mr. Rubin's SSI on bottled vs. tap water due to the question raised in his SJSP unit of study regarding whether one was better, healthier, or otherwise cleaner than the other. This was important in making sure his SJSP unit of study was a cohesive blend of STEM Content and Sociocultural Context. These findings are complementary to the case study of Tsurusaki et al. (2013), who explored the culturally relevant science teaching practices exhibited by a 6th grade teacher in an urban school in the midwestern United States through video-taped classroom observations, field notes, student work artifacts, and student focus-group interviews over 13 class periods. Tsurusaki et al. found that the teacher had students collect data pertaining to students' own fast-food eating habits and analyze it by comparing it to class data and national guidelines using a bar graph. This is similar to the way Mr. Rubin had his students engage in data collection and analysis in that both Mr. Rubin and the teacher from Tsurusaki et al. connected the data and resulting analysis to a sociocultural context that was used to frame the lesson. In fact, Tsuruki et al. saw their teacher continue to build on the data students had collected and analyze to get them to think more deeply about the sociocultural context, specifically in terms of reasons people might eat at fast food, and why some would not be in-line with national guidelines. This way of blending content with context seen in Tsurusaki et al. is also similar to findings from this study.

That is not to say, however, that teachers did not experience challenges in moving students through this process. Both Ms. Rossi and Mr. Rubin expressed difficulties in having students make sense of the data they worked with in class, although they responded to these challenges in different ways. On the one hand Ms. Rossi expressed an intention to provide more scaffolds to her students in using data and evidence to support a claim, Mr. Rubin expressed an intention to bring in a guest speaker, ideally an expert in the field of water quality, in order to help his students with their conceptual understanding of the data and the content. This shows that J-STEM teachers' PCK of STEM Content, particularly in terms of the ways in which they facilitate their students' exploration and analysis of data differ, which may be attributable to PCK being such a highly particularized form of teacher knowledge (Gess-Newsome, 2015).

It is also worth pointing out the ways in which the J-STEM program prepared teachers to work with their students to collect and analyze data related to an organizing SSI. In the speed-limit SSI workshop described in chapter 3, teachers at one station were tasked with analyzing previously collected data to determine how different variables such as surface condition, mass of car, and turning radius affected the maximum safe speed of a moving car. Similar to the examples above of Mr. Rubin and Tsurusaki et al. (2013), this data was related to the organizing sociocultural context of the SSI around speed limits and safety. After J-STEM teachers completed the analysis, they engaged in discussions around the validity of the data and whether the data was sufficient in making a claim around speed limits. Teachers' analysis of data naturally led to questions around how factors not included in the data set might impact safe driving speed, such as time of day and driving experience. It also led to discussions relating to the sociocultural context, such as whether or not individuals would follow the speed limit, and whether the posted speed limit should be artificially lowered to account for people not wanting to follow the speed limit rules. This blending of content and context seen throughout the findings in this study may suggest the overlapping nature of the PCK of SJSP domains. Additionally, conversations and discussions emerging from the confluence of STEM content with sociocultural context can result in problematization of issues related to the SSI to surface issues of injustice. Teachers' PCK of Problematization as seen in this study are discussed in the following section.

PCK of Problematization

Findings from this study showed that teachers expressed their PCK of Problematization by engaging in reflexivity, dialogic conversation, magnification and comparative localization. Through these practices, teachers in this study guided their students to surface issues of injustice inherent in the SSI organizing their SJSP units of study. Ways in which teachers navigated each of these themes are discussed in the subsections that follow.

Reflexivity

Findings from this study suggest that teachers' engagement of students in reflexivity (Rodriguez, 1998) was a helpful starting point for students to dig deeper into the nuances within the sociocultural context associated with the organizing SSI revealed through multiple perspectives, with teachers in this study exhibiting their PCK of reflexivity in different ways. For example, Ms. Moretti expressed her PCK of reflexivity in the way she structured her unit of study in such a way where students were prompted to reflect and consider how they felt after a planned unfair situation within a learning activity demonstrating inequities in fast fashion practices across the globe, whereas Ms. Rossi chose to engage students in activities to precipitate student thinking about whose voices and perspectives hold societal power. Interestingly, these activities were unlike those seen in the J-STEM PD, where teachers engaged in reflexivity through activities such as the identity collage, as described in chapter 3, in which participants created a collage of images that resonated with them and allowed them to share aspects of their identity and culture by sharing and talking about their collages with peers. However, through both Ms. Moretti's and Ms. Rossi's activities, students were still required to think about how an individual's background and experiences influence the way they reason and make important decisions, and the impact of those decisions relative to the SSI used to organize the SJSP unit of study.

These findings are similar to the study of Morales-Doyle (2020), which explored the experiences of high school chemistry students engaged in an SJSP unit of study around aspirin through student interviews and work samples and the teacher's (who was also the researcher, Morales-Doyle) archival notes. In this study, Morales-Doyle saw students problematize colonialism in Western medicine and its role in erasing and minimizing contributions from indigenous groups by noting the differences in how the synthetic compound, aspirin, is recognized by the western medical community, whereas knowledge possessed by Native American societies who had been using the compound in its naturally occurring form in willow bark since before the synthesis of aspirin was dismissed by Western medicine as inconsequential and unscientific. This focus on whose voices are heard and given power by mainstream society is similar to Ms. Rossi's fast fashion learning activities described above, as both her students and those of Morales-Doyle considered how people's backgrounds inform their own perspectives and the perspectives they deem credible.

This openness to considering where others are coming from and where oneself might be coming from as well, may also have made it easier for teachers to facilitate dialogic conversations that revealed issues of injustice, as discussed in the following subsection.

Dialogic Conversation

Findings from this study indicate that teachers expressed PCK of Problematization through engaging students in dialogic conversations that allowed students to surface issues of injustice related to the organizing SSI at the center of teachers' SJSP unit of study through conversation. For example, Mr. Rubin engaged students in dialogic conversations by structuring small group discussions around pros and cons of plastic water bottles and holding students accountable for participating by requiring them to document the outcome of said discussion on chart paper. Ms. Moretti, on the other hand, did not so much enumerate a series of structured discussion activities as reflect on how the classroom norms she established for discussions around mutual respect and creating a “safe space” for dialogue allowed her students to build on less structured conversations over the course of the SJSP unit of study in which issues of injustice surfaced naturally during these dialogic conversations. Although Ms. Moretti and Mr. Rubin both engaged students in dialogic conversations, they did so in different ways, suggesting they may possess slightly different PCK around dialogic conversations and problematization in general

Another, slightly different method for engaging students in dialogic conversations was seen by Tsurusaki et al. (2013), who noted in their case study that the 6th grade science teacher (discussed earlier in the Data Collection and Analysis subsection) was able to spark a number of discussions among her students about the content of their food by having them analyze food labels. Tsurusaki et al. described these discussions as resulting organically from activities students engaged in where they were asked to look at the different labels on foods they liked to eat or had at home and analyzed their nutritional content and serving size. Upon realizing that a favorite snack, Cheetos, did not in fact have any cheese, student interest was so high that the teacher allowed conversations to continue even after the unit had ended, and Tusursaki et al. noted that many students changed their eating habits as a result. This surge in interest and willingness to engage in discussion is similar to what Ms. Rossi observed in her classroom, reflecting that, due to the highway speed camera SSI she selected being high-interest for students, there discussions emerging from that SSI were “almost too engaging,” noting that it was sometimes difficult to steer emerging class conversations about street racing back toward the STEM content underlying the SSI. At the same time, teachers in Bossér et al.’s (2015) study of two high school teachers enactment of SSI within a high school social studies course in Sweden noted the opposite problem, in that few students, if any, were willing to engage in discussions. Bossér et al. attributed that to the lack of relevance in the examples and discussion prompts the teachers used with students. This attribution resonates with the findings of this study and of Tsurusaki et al., both of which saw heightened student engagement in discussions of relevant SSIs.

In cultivating teachers’ capacity for dialogic conversation, the J-STEM program involved regular critical discussions of local news articles covering topics such as construction projects, climate change, homelessness, and inflation during each PLC session. From these dialogic conversations, teachers worked together to unpack issues of injustice, STEM content, and ways of incorporating local news articles such as the one currently under discussion in their own classrooms with their own students. In many of these conversations, one of the points teachers continued to come back to was how relevant the different articles and SSIs might be to their students. Similar to the findings of this study, of Tsurusaki et al. (2013), and of Bossér et al. (2015), in these dialogic conversations teachers’ engaged in throughout the J-STEM PD, teachers linked perceived relevance of an SSI to students with the degree to which they predicted students would engage in conversation (and other learning activities for that matter) around the SSI.

Magnification

Findings from this study indicate that teachers were able to problematize SSI with their students through magnification. For example, Ms. Moretti and Mr. Rubin exhibited their PCK of magnification by generalizing an SSI to a global scale. While both Ms. Moretti and Mr. Rubin had SSIs that, in some way, shape, or form, revolved around water usage and pollution, differences in their PCK emerged in their chosen starting points for magnification. Ms. Moretti began by utilizing current events to generalize the issue of a particular water crisis in a specific city to connect to the issue of access to clean drinking water on a global scale. Mr. Rubin, while still choosing to generalize to a global scale, began with student data from a classroom water quality investigation, asking students to think through potential impacts of their data on their own communities, and then generalizing worldwide. In both cases, teachers noted that students were able to more clearly understand the nuances of the SSI when thinking about them at scale. Ms. Moretti and Mr. Rubin's use of magnification in this way is similar to the way that Gutstein (2007) problematized local housing developments with his students by having students engage in mathematical problem solving, beginning with calculating median income in a particular city and ending with making a claim about gentrification grounded in mathematical applications of numerical income and housing data. A notable difference, however, is that while Mr. Rubin and Ms. Moretti started with a specific context and generalized to a global context, Gutstein began with a more abstract mathematical proposition about the relationship between income and housing affordability and had students particularize this understanding in application to the specific context of their own city. Other differences worth noting are that Gutstein's study was focused on himself as a 7th grade mathematics teacher, whereas the teachers in this study were teachers of science.

Within the J-STEM PD program, magnification was not an intentional focus, being that it was not a part of the initial SJSP framework used during the program. However, elements of magnification were still present in some of the J-STEM workshops and activities in which teachers participated. For example, in exploring the SSI of whether or not a plastic bag ban was a good idea, teachers' began by thinking about the impending plastic bag ban in the neighboring city where many of them taught, and over the course of the activity teachers were guided to think on a more general scale about the lifecycle of a plastic bag and to consider the great Pacific garbage patch, a collection of micro plastics polluting the Pacific ocean, through videos, articles, and discussions. Additionally, in a later workshop, teachers participated in a “fish game” activity, where teachers worked in groups to model sustainable fishing practices by taking a number of “fish” out of the center “pond” in turn each round, after which a set number of fish were replenished. Engaging in this activity prompted participants to consider, “what if everyone fished like you?” Both of these activities relate to magnification because of the way they structure participants' focus to move from a particular context (e.g., their city or their pond) to a more generalized context (e.g., great pacific garbage patch, whole oceans).

Comparative Localization

Findings from this study show that teachers utilized comparative localization to further reveal issues of injustice and inequity relative to the SSI at the center of their SJSP unit of study. Ms. Rossi guided students to examine a high-profile energy crisis in another state and think through implications, similarities and differences that could play out if a similar crisis were to occur in the students' own city. Ms. Moretti expressed her PCK by having students use a graphic organizer to compare how the same SSI (fast fashion) was unfolding in three different countries. Like Ms. Rossi, Ms. Moretti is able to reveal the nuances of the SSI by shifting focus from one context to another, but unlike Ms. Rossi, who had students consider hypothetical implications, Ms. Moretti had students consider concrete implications currently playing out across the world. Mr. Rubin expressed his PCK in having students compare and contrast a high-profile water crisis happening in another part of the country with a smaller-scale water quality scare that took place in the students' own city. Similar to Ms. Moretti, Mr. Rubin is making use of current, as opposed to hypothetical, events for his students to consider, but unlike Ms. Moretti, though similar to Ms. Rossi, Mr. Rubin is having students compare a non-local manifestation of the SSI to a local manifestation of the SSI.

Gutstein (2007) also engaged his 8th grade mathematics students in problematizing the Mercator projection of the world map by having them calculate and compare the areas of sets of countries in terms of the area of Mexico as a unit of measurement. After finishing the activity, students realized that the world map they were used to seeing inaccurately represented the relative sizes of different countries and continents (e.g., Mexico and Africa both appear smaller than they really are, whereas Alaska and Greenland both appear larger than they really are). This way of comparing similar aspects of different contexts to surface injustice is complementary to the findings of this study, which showed all three teachers engaging students in some form of comparative localization.

As with magnification, the J-STEM PD did not intentionally incorporate examples of comparative localization as it was not a part of the initial J-STEM framework. However, teachers were exposed to ideas in-line with comparative localization through one of the J-STEM guest speaker presentations on community based math projects. In this presentation, the speaker gave examples of social justice oriented mathematics activities that could be used in classrooms, such as comparing neighborhood data based on number of vacant lots vs. number of basketball courts and comparing average daily attendance rates with four-year graduation rates for different types of high schools in the city in which many of the J-STEM teachers teach. While this is different than the comparative localization seen in this study, where teachers compared how an SSI unfolded in different geographic contexts, it is still worth highlighting here due to the emphasis on comparing and contrasting how a particular trend unfolded within different microcosms of the same locale. In fact, it is possible that participants may have taken inspiration from activities such as this within the J-STEM program in order to plan their learning activities that involved comparative localization.

PCK of Agency & Action

Despite there being few examples of STEM teaching that engage students in social justice projects and empower and support them to successfully address such issues outside of the classroom (Boutte & Kelly-Jackson, 2010; Dimick, 2012; Morales-Doyle, 2017), the J-STEM PD program sought to do just that, in part by exposing teachers to new strategies such as using the root cause tree described in chapter 3, as well as through field trips and guest presenters from community organizations. Teachers in this study reflected on both successes and challenges relating to their ability to have students elucidate their own position or solution relative to the organizing SSI within the SJSP unit of study, as well as with their desires to, and experiences with, engaging students in community improvement projects to facilitate students making a difference in their own communities related to the SSI.

Elucidate Own Position/Solution

Findings from this study illustrate how teachers supported students in elucidating their own position/solution with respect to the focal SSI within their SJSP unit of study. Mr. Rubin was able to have students elucidate their own position relating to the SSI by polling student opinion at different points in the SJSP unit of study as students learned more information. This is similar to Sadler et al. (2019), who describe a socioscientific unit of study around a vanishing prairie as an example of climate change; students voiced their positions on the issue of climate change at various points throughout the unit so students had opportunities to reflect on how their opinions might have changed. Ms. Moretti also saw success in that her students reported an intention to make changes in their lives in terms of personal decisions they would make around the fast fashion SSI due to the learning that took place in the SJSP unit of study.

In the J-STEM program, teachers' participated in a variety of SSI activities where they elucidated their own position/solution. These included the speed limit activity, gerrymandering activity, and the role of mask mandates in stopping the spread of disease, all of which are described in chapter 3. Through these activities, teachers' generally began by voicing their own opinion relating to the SSI, and then again after engaging in readings, modeling activities, and discussions, elucidated their own position/solution with respect to the SSI for a second time at the conclusion of the activity. Teachers also saw from the J-STEM PD sessions different ways of elucidating students' opinions, such as through argument lines (Kahn, 2019), debates, and digital tools like Padlet and Jamboard.

In addition to elucidating their own position or solution, teachers in this study sought to develop student's capacity for agency and action through engaging students in community improvement projects. The PCK teachers exhibited through working with students on these types of projects is discussed in the following subsection.

Community Improvement Projects

In addition to the success with having students elucidate their own position/solution with respect to the SSI, findings from this study showed teachers' belief of the value of using community improvement projects as a way to extend students' learning beyond the walls of the classroom. While all three teachers in this study expressed an intention to engage students in community improvement projects, not all were successful. For example, while Ms. Moretti was able to conceptualize and plan for a community improvement project where students would lead a clothing recycling drive for their school community, this effort was ultimately unsuccessful due to contextual issues such as securing space in her school building in which to house the clothes they planned to collect. Similarly, Dimick (2012) also saw a teacher struggle with enacting a community improvement project with public charter high school students aimed at an environmental cleanup in a local river ecosystem. While Dimick's teacher struggled due to factors relating to the teacher's ability to engage the students and hold them accountable for productively working together, Ms. Moretti's struggles were more logistical in nature, having more to do with factors outside her classroom but related to school-building level issues of space. Like Ms. Moretti, Ms. Rossi reflected on challenges with engaging students in activities that extended learning beyond the walls of the classroom. In particular, Ms. Rossi noted challenges with getting students to think beyond final classroom activity, expressing a desire to empower them to take some meaningful action relative to the SSI. Mr. Rubin, on the other hand, had more success with his community improvement project, engaging students in an anti-littering campaign by collaborating with a community partner to have students label storm-drains in their neighborhood-community that fed into their local watershed. This difference in success speaks to the importance of teachers' knowledge and familiarity with contextual factors (i.e., availability of space in the school-building for different types of projects and events), an important aspect of PCK (Gess-Newsome, 1999).

The J-STEM PD program did include sessions relating to community improvement projects, from which teachers in this study may have drawn inspiration. For example, one of the J-STEM teachers developed and facilitated a J-STEM workshop for others in her cohort on the value service learning projects and tips to enact them in STEM classes. In this workshop, teachers learned tips and tricks for engaging students in community improvement projects based on teachers' organizing SSI within their SJSP unit of study, including how to identify and make use of resources currently available to teachers so as not to have to reinvent the wheel unnecessarily.

Conceptual Framework Evolution

While not the focus of this study, one important byproduct of my work in this study and previous studies leading up to it (i.e., Macalalag, Johnson et al., 2023; Macalalag, Minken et al., 2023; Macalalag, Minken, & Varma, 2023; Minken et al., 2020; Minken et al., 2021; Minken et al., 2024; Minken & Macalalag, 2021) has been the development and evolution of the conceptual framework as seen now in this study. The initial research I was involved in was simply the application of Sadler et al.'s (2019) SSI framework, broken down into 7 components. In subsequent research (Minken et al., 2021), our analysis revealed how teachers emphasized different aspects of Sadler et al.'s SSI framework in different ways, leading us to categorize these seven components into more general aspects of the SSI framework: social aspects, scientific aspects, and discursive aspects. When the opportunity came to work on developing the J-STEM program, one of the focuses was social justice using SSI. As one might imagine, and as others have articulated (e.g., Dos Santos, 2009; Morales-Doyle, 2017), SSI lends well to a social justice pedagogy that can be enacted within STEM education. However, SSI lessons based on Sadler et al.'s framework do not necessarily have to involve student exploration and resolution of issues of injustice related to the SSI. For instance, an SSI unit of study examining a tax on sugary drinks can look at social aspects such as economic systems and multiple stakeholder perspectives of those impacted by such a tax, scientific aspects such as macromolecules and nutrition, and involve discursive aspects in which students reflect on the SSI and ultimately elucidate their own position or alternative solution with respect to such a sugar tax. However, issues of whether or not this was an appropriate way to improve the health of residents of a large city, many of whom may be living in areas of concentrated poverty where there are a dearth of healthy food options (otherwise known as a food desert) may be left unexplored in such an SSI unit of study. Therefore, the J-STEM team sought to augment Sadler et al.'s SSI framework to focus more explicitly on social justice. Eventually, we settled on Alberto Rodriguez's (1998) theory of sociotransformative constructivism (sTc), which seeks to combine theories of learning and social justice, and was specifically applied to STEM education. This combination SSI/sTc framework served as a blueprint for social-justice oriented SSI within the J-STEM program, and consisted of the three previously mentioned aspects (social, scientific, and discursive), and an additional aspect, justice, which involved the sTc components of authentic activity, dialogic conversation, reflexivity, and metacognition. In preparing for this study, after reviewing the literature intersecting social justice oriented STEM education and PCK, I felt it necessary to re-imagine J-STEM's SSI/sTc framework by more thoroughly infusing sTc into SSI with the purpose of highlighting the general components of social justice STEM education I saw in the literature base. This reorganization of SSI/sTc into the PCK of SJSP conceptual framework used in this dissertation study emphasized the importance of problematizing SSI to surface issues of injustice and purposefully extending student learning beyond the walls of the classroom through developing and supporting students' agency and action in this process. In concluding this study, I see how this re-orienting of SSI/sTc revealed additional important components of SJSP important for teachers' practice such as magnification, comparative localization, and an emphasis on community improvement projects. In the following sections, I will discuss limitations, implications, and recommendations for future research based on my findings from this study.

Limitations

As with any research study, this study had several factors inherent in its design that may limit the degree to which the findings here can be generalized to other contexts. First, it is important to note that, while this study explored and analyzed teachers' PCK of SJSP, the teachers in this study were all science teachers of science. While this still qualifies these teachers as STEM teachers, the PCK of SJSP expressed by a science teacher may be different from that of a mathematics or technology teacher, despite the fact that all such teachers can be considered STEM teachers. Additionally, these teachers all taught within the same urban school district, and as such their PCK of SJSP captured in this study may be different from the PCK of SJSP that might be expressed by teachers in other contexts. Finally, teachers in this study had already self-selected to join an intensive two-year professional development program designed to cultivate teachers' PCK of SJSP. As such, these teachers' PCK of SJSP may have developed in certain ways due to their participation in the J-STEM program based on features of SJSP that the program emphasized. Additionally, these teachers may have been more receptive to developing this PCK than teachers who did not self-select into the J-STEM program.

Implications and Recommendations for Future Research

The findings for this study may suggest several implications for practice, both for classroom educators and for providers of professional learning opportunities. First, teachers can make STEM learning more authentic to students by including student voice and working with community partners to support with socioscientific issues-based instruction. In the J-STEM PD program, teachers engaged in a number of potential, local community partner organizations through field trips and guest speakers. These included trips to a local arboretum and guest speakers who did workshops around creating and testing engineering models of medical storage devices. Interestingly, all three participants either engaged with community partners through their SJSP unit of study, or expressed an intention to do so in redeveloping their unit. When planning SJSP units of study, teachers should organize such units around socioscientific issues which culminate in student-driven community improvement projects. Additionally, more professional learning opportunities are needed for pre-service and in-service STEM teachers that focus on SJSP, especially with respect to the domains of Problematization and Agency & Action. In the J-STEM PD, teachers engaged in regular reflection and dialogical conversations while debriefing instructional techniques and strategies, such as the use of argument lines in structuring debates, and thinking through how these strategies could work in their own classrooms, and sharing these insights with their peers. In effect, teachers were engaging in magnification and comparative localization with respect to the different SJSP teaching methods they participated in throughout the program. These aspects of problematization could be further strengthened by purposefully applying the concepts of magnification and comparative localization to the different SSI used in the J-STEM PD. For example, the speed limit activity described in chapter 3 could be modified to encourage participants to compare the implications of adjusting speed limits in different settings (e.g., rural, urban, suburban), as well as looking at data associated with places like Germany's Autobahn that do not enforce speed limits, and then discussing the implications of replicating those driving regulations worldwide. In particular, teachers may benefit from support in facilitating dialogic conversations with students in which they are guided to problematize SSIs through magnification and comparative localization. These professional learning opportunities should also be structured in a way as to connect teachers with community partners local to their school-community that may be able to assist teachers in developing and implementing ideas for community improvement projects in which teachers' students could participate as part of teachers' SJSP units of study.

More research is needed to better understand teachers' PCK of SJSP, and the relationship between SJSP and student learning. While this was a qualitative case study exploring the PCK of three different teachers who participated in the J-STEM PD program, grounded in data that illuminated teacher knowledge and perceptions, and well suited to answering the research questions outlined in chapter 3 and in the beginning of this chapter as well, there remain a number of research problems in need of attention. For instance, the teacher-created SJSP units of study involve decision making, but this study did not assess students' STEM literacy skills nor democratic problem solving, an important focus in integrated STEM education (Mohr-Schroeder et al., 2020). According to Barton and Tan (2011), democratic science teaching values scientific literacy as vital for informed participation in democratic societies, and as such is designed to empower students to use and apply their scientific knowledge to improve their lives and communities. In focusing more on teachers' PCK within the SJSP domain of Agency & Action, future research in SJSP could explore ways that teachers integrate principles of democratic science education, such as voice, authority, and critical science literacy, as described by Barton and Tan, into their teaching practice.

Future research might also consider analyzing teachers' use of the NGSS science and engineering practices (NGSS Lead States, 2013) within an SJSP unit of study as one way of better understanding how teachers' PCK supported students' STEM literacy. One way to do this could be through the use of the EQuiP rubric (Achieve, Inc., 2016) to assess science teachers' lesson plan alignment with the NGSS. Additionally, this study did not focus on teachers' use of assessment tools and techniques to gauge students' STEM literacy skills, a frequent struggle for

STEM teachers (Cian et al., 2019). This could be studied through an explicit focus on how teachers' assess the different strands of the NGSS within SJSP units of study. Previously, McElhaney et al. (2017) developed criteria that can be used to develop such assessments.

In order to pursue the answers to such research problems, it could be useful to collect student data in the form of focus groups, small-group observations, and work samples that illustrate students' STEM literacy skills described by the NGSS science and engineering practices (NGSS Lead States, 2013) against the backdrop of a STEM literacy framework such as that put forth by Mohr-Schroeder et al. (2020) or Owens and Sadler (2020). Additionally, while this study focused on teachers' PCK of SJSP, it did not explore the ways in which teachers integrated different STEM content such as engineering design into their teaching practice, a noted challenge for teaching integrated STEM (Crotty et al., 2017). In addressing this issue, a study similar to this one, but with a focus on integrated STEM in the context of SJSP, could prove insightful. While the types of data sources could be similar, the data collection instruments should be aligned with practices that support scientific, technological, engineering, and mathematical literacy both separately (CCSSI, 2010; ITEEA, 2020; NRC, 2012; NGSS Lead States, 2013) and holistically (Cavalcanti, 2017; Mohr-Schroeder, 2020; Owens & Sadler, 2020; Zollman, 2012). Just as importantly, this study did not explore teachers' successes and challenges with shifting their mindset, cultural misunderstandings, or addressing their own cultural biases when enacting SJSP, all common struggles for teachers (Olayemi & DeBoer, 2021). Mensah (2009) found the use of book clubs with pre-service science teachers to be a useful way to reveal and address cultural biases teachers had related to science and science education. This problem could be addressed through qualitative research focused on exploring "teachers' conception of themselves and others; their conception of knowledge; and how they structured social relations and interactions in the classroom" (Olayemi & DeBoer, 2021, p. 6) in the context of developing and implementing SJSP units of study.

Finally, further research could be beneficial in more deeply exploring some of the themes that emerged in this study to show how teachers can problematize issues of injustice for their students, including the concepts of magnification and comparative localization put forth in this study, how teachers can engage effectively with community partners, how teachers can successfully implement STEM-focused community improvement projects, and the supports most critical to teacher and student success in these endeavors. This study was a qualitative case study exploring the PCK of three different teachers who participated in the J-STEM PD program grounded in data that illuminated teacher knowledge and perceptions. While helpful in answering my research questions, more research is needed to illuminate students' responses, reactions, and engagement to different aspects of these SJSP units of study. While such research is currently underway by J-STEM affiliated researchers, student data such as focus groups, small-group observations, and work samples may serve to deepen theoretical understandings of teachers' PCK of Problematization and Agency & Action. Despite teaching being an act that includes teachers and students, because of the focus in this study on *teacher* knowledge, no student data was collected, and as such no conclusions can be firmly drawn regarding the impact of teachers' PCK of SJSP on students. It is also worth noting that simply possessing a high degree of PCK does not guarantee effective classroom practice.

References

Achieve, Inc. (2016). EQuIP rubric for lessons & units: Science version 3.0. https://www.nextgenscience.org/sites/default/files/EQuIPRubricforSciencev3.pdf

Aikenhead, G. S. (1984). Teacher decision making: The case of Prairie High. *Journal of Research in Science Teaching, 21*(2), 167–168. https://doi.org/10.1002/tea.3660210208

Aikenhead, G. S. (1985). Collective decision making in the social context of science. *Science Education, 69*(4), 453–475. https://doi.org/10.1002/sce.3730690403

Aikenhead, G. (1992). The integration of STS into science education. *Theory Into Practice, 31*(1), 27–35. https://doi.org/10.1080/00405849209543521

Aikenhead, G. S. (2003). STS education: A rose by any other name. In R. Cross (Ed.), *A vision for science education: Responding to the work of Peter J. Fensham* (pp. 59–75). Routledge.

America at the turn of the century: A look at the historical context. (n.d.) *Library of Congress, The Life of a City: Early Films of New York, 1898 to 1906* [Collection]. https://www.loc.gov/collections/early-films-of-new-york-1898-to-1906/articles-and-essays/america-at-the-turn-of-the-century-a-look-at-the-historical-context/

American Association for the Advancement of Science. (1990). *Science for all Americans.*

Ball, D. L., Thames, M. H., Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389–407. https://doi.org/10.1177/0022487108324554

Barendsen, E., & Henze, I. (2019). Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education, 49*, 1141–1175. https://doi.org/10.1007/s11165-017-9637-z

Barrett, S. E., & Nieswandt, M. (2010). Teaching about ethics through socioscientific issues in physics and chemistry: Teacher candidate's beliefs. *Journal of Research in Science Teaching, 47*(4), 380–401. https://doi.org/10.1002/tea.20343

Barton, A. C., & Osborne, M. D. (2002). Reconstructing the harsh world: Science with/for social action. *Counterpoints, 210*, 167–184.

Barton, A. C., & Tan, E. (2011). Why democratic science teaching matters. In S. J. Basu, A. C. Barton, & E. Tan (Eds.), *Democratic science teaching: Building the expertise to empower low-income minority youth in society* (pp. 115–120). Sense Publishers.

Bartousis, A., McGregor, G., & Mills, M. (2016). Pedagogic voice: Student voice in teaching and engagement pedagogies. *Pedagogy, Culture, & Society, 24*(1), 123–140. https://doi.org/10.1080/14681366.2015.1087044

Basile, V., & Azevedo, F. S. (2022). Ideology in the mirror: A loving (self) critique of our equity and social justice efforts in STEM education. *Science Education, 106*, 1084–1096. https://doi.org/10.1002/sce.21731

Bender, E., Hubwieser, P., Schaper, N., Margaritis, M., Berges, M., Ohrndorf, L., Magenheim, J., & Schubert, S. (2015). Towards a competency model for teaching computer science. *Peabody Journal of Education, 90(*4), 519–532. https://doi.org/10.1080/0161956X.2015.1068082

Berland, L. K. (2013). Designing STEM for integration. *Journal of Pre-College Engineering Education Research, 3*(1), Article 3. https://doi.org/10.7771/2157-9288.1078

Bossér, U., Lundin, M., Lindahl, M., & Linder, C. (2015). Challenges faced by teachers implementing socio-scientific issues as core elements in their classroom practice.

European Journal of Science and Mathematics Education, 3(2), 159–176. https://doi.org/10.30935/scimath/9429

Boutte, G., & Kelly-Jackson, C. (2010). Culturally relevant teaching in science classrooms: Addressing academic achievement, cultural competence, and critical consciousness. *International Journal of Multicultural Education, 12*(2).

Boyles, D., Carusi, T., & Attick, D. (2009). Historical and critical interpretations of social justice. In W. Ayers, T. Quinn, & D. Stovall (Eds.), *Handbook of Social Justice in Education* (pp. 30–42). Routledge.

Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2019). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. *Urban Education, 54*(6), 775–803. https://doi.org/org/10.1177/0042085918794802

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30–35.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Association.

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education, 25*(2), 211–221. https://doi.org/10.1007/s10972-014-9381-4

Bybee, R. W., & Landes, N. M. (1990). Science for life & living: An elementary school science program from Biological sciences curriculum study. *The American Biology Teacher, 52*(2), 92–98. https://doi.org/10.2307/4449042

Carlson, J., & Daehler, K. R. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77–94). Springer. https://doi.org/10.1007/978-981-13-5898-2_2

Casper, A. M. A., & Balgopal, M. M. (2020). How guest speakers tell stories about environmental socio-scientific issues in an undergraduate class. *International Journal of Science Education, 42*(9), 1568–1584. https://doi.org/10.1080/09500693.2020.1772519

Cavalcanti, M. A. L. (2017). *Assessing STEM literacy in an informal learning environment* [Doctoral dissertation, University of Kentucky]. UKnowledge Theses and Dissertations–Education Science. https://doi.org/10.13023/ETD.2017.062

Chadderton, C. (2012). Problematising the role of the white researcher in social justice research. *Ethnography and Education, 7*(3), 363–380. https://doi.org/10.1080/17457823.2012.717203

Chandler, J., Fontenot, A. D., & Tate, D. (2011). Problems associated with a lack of cohesive policy in k-12 pre-college engineering. *Journal of Pre-College Engineering Education Research, 1*(1), Article 5. https://doi.org/10.7771/2157-9288.1029

Chang, J., & Park, J. (2020). Developing teacher professionalism for teaching socio-scientific issues: What and how should teachers learn? *Cultural Studies of Science Education, 15*, 423–431. https://doi.org/10.1007/s11422-019-09955-6

Cian, H., Marshall, J., & Cook, M. (2019). Formatively assessing NGSS: Three models of formative assessment for addressing NGSS domains. *The Science Teacher, 86*(6), 44–49.

Cochran-Smith, M., Shakman, K., Jong, C., Terrell, D. G., Barnatt, J., & McQuilian, P. (2009). Good and just teaching: The case for social justice in teacher education. *American Journal of Education, 115*(3), 347–377. https://doi.org/10.1086/597493

Common Core State Standards Initiative (2010). *Common core state standards for mathematics*. National Governors Association & Chief State School Officers. http://www.corestandards.org/wp-content/uploads/Math_Standards1.pdf

Cunningham, C. M., Lachappelle, C. P., Brennan, R. T., Kelly, G. J., Tunis, C. S. A., & Gentry, C. A. (2020). The impact of engineering curriculum design principles on elementary students' engineering and science learning. *Journal of Research in Science Teaching, 57*(30), 423–453. https://doi.org/10.1002/tea.21601

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry & research design: Choosing among five approaches* (4th ed.). Sage.

Crotty, E. A., Guzey, S. S., Roehig, G. H., Glancy, A. W., & Ring-Whalen, E. A. (2017). Approaches to integrating engineering in STEM units and student achievement gains. *Journal of Pre-College Engineering Education Research, 7*(2), Article 1. https://doi.org/10.7771/2157-9288.1148

de Vries, M. J. (2018). Technology education: An international history. In M. J. de Vries (Ed.), *Handbook of technology education* (pp. 73–84). Springer. https://doi.org/10.1007/978-3-319-44687-5_8

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice.* Teachers College Press.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601. https://doi.org/10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

DePiper, J. N., & Driscoll, M. (2018). Teacher knowledge and visual access to mathematics. In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in STEM: Research into practice* (pp. 83–102). Springer. https://doi.org/10.1007/978-3-319-97475-0_5

Deniz, H., & Adibelli, E. (2015). Exploring how second grade elementary teachers translate their nature of science views into classroom practice after a graduate level nature of science course. *Research in Science Education*, 45, 867–888. https://doi.org/10.1007/s11165-014-9447-5

Dimick, A. S. (2012). Student empowerment in an environmental science classroom: Toward a framework for social justice science education. *Science Education, 96*(6), 990–1012. https://doi.org/10.1002/sce.21035

Dodo Seriki, V. (2018). Advancing alternate tools: Why science education needs CRP and CRT. *Cultural Studies of Science Education, 13*, 93–100. https://doi.org/10.1007/s11422-016-9775-z

Dos Santos, W. L. P. (2009). Scientific literacy: A Freirean perspective as a radical view of humanistic science education. *Science Education, 92*(2), 361–382. https://doi.org/10.1002/sce.20301

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Open University Press.

Driver, R. Newton, P., Osbourne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Esposito, J., & Swain, A. N. (2009). Pathways to social justice: Urban teachers' use of culturally relevant pedagogy as a conduit for teaching for social justice. *Perspectives on Urban Education, 6*(1), 38–48.

Ewing, M., & Sadler, T. D. (2020). Socio-scientific issues instruction: An interdisciplinary approach to increase relevance and systems thinking. *The Science Teacher, 88*(2), 18–21.

Fadzil, H. M. (2017). Exploring early childhood preservice teachers' problem-solving skills through socioscientific inquiry approach. *Asia-Pacific Forum on Science Learning and Teaching, 18*(1), Article 9.

Feynman, R. P. (1965). New textbooks for "new" mathematics. *Science and Engineering, 28*(6), 9–15. https://resolver.caltech.edu/CaltechES:28.6.0

Friedrichsen, P., & Berry, A. (2015). Science teacher PCK learning progressions: Promises and challenges. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 214–228). Routledge.

Fielding, M. (2004). Transformational approaches to student voice: Theoretical underpinnings, recalcitrant realities. *British Educational Journal, 30*(2), 295–311. https://doi.org/10.1080/0141192042000195236

Freire, P. (2000). *The pedagogy of the oppressed* (30th Anniversary Edition). Continuum. (Original work published in 1970)

Gale, J., Koval, J., Ryan, M., Usselman, M., & Wind, S. (2019). Implementing NGSS engineering disciplinary core ideas in middle school science classrooms: Results from the field. *Journal of Pre-College Engineering Education Research, 9*(1), 11–29. https://doi.org/10.7771/2157-9288.1185

Gallagher, J. J. (1971). A broader base for science teaching. *Science Education, 55*(3), 329–338. https://doi.org/10.1002/sce.3730550312

Galletta, A. (2013). *Mastering the semi-structured interview and beyond: From research design to analysis and publication*. New York University Press. https://doi.org/10.18574/nyu/9780814732939.001.0001

Garibay, J. C. (2015). STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students? *Journal of Research in Science Teaching, 52*(5), 610–632. https://doi.org/10.1002/tea.21203

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3–17). Kluwer Academic Publishers.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28–42). Routledge.

Gewirtz, S. (1998). Conceptualizing social justice in education: mapping the territory. *Journal of Education Policy, 13*(4) 469–484. https://doi.org/10.1080/0268093980130402

Grossman, P. (1990). *The making of a teacher: Teacher knowledge & teacher education.* Teachers College Press.

Gunstone, R. F. (2015). Re-examining PCK: A personal commentary. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 245–255). Routledge.

Gutstein, E. (2003). Teaching and learning mathematics for social justice in an urban, Latino school. *Journal for Research in Mathematics Education, 34*(1), 37–73. https://doi.org/10.2307/30034699

Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. Routledge.

Gutstein, E. (2007). "And that's just how it starts": Teaching mathematics and developing student agency. *Teachers College Record, 109*(2), 420–448. https://doi.org/10.1177/016146810710900203

Guzey, S. S., Caskurlu, S., & Kozan, K. (2020). Integrated STEM pedagogies and student learning. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research in STEM education* (pp. 65–75). Routledge. https://doi.org/10.4324/9780429021381-8

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research, 6*(1), 11–29. https://doi.org/10.7771/2157-9288.1129

Henze, I., & Van Driel, J. H. (2015). Toward a more comprehensive way to capture PCK in its complexity. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 120–134). Routledge.

Hekimoglu, S., & Sloan, M. (2005). A compendium of views on the NCTM standards. *The Mathematics Educator, 15*(1), 35–43.

Herrera, T. A., & Owens, D. T. (2001). The "new new math"?: Two reform movements in mathematics education. *Theory Into Practice, 40*(2), 84–92. https://doi.org/10.1207/s15430421tip4002_2

Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. *International Journal of Environmental & Science Education, 4*(3), 275–288.

Holbrook, J., & Rannikmae, M. (2017). Context-based teaching and socio-scientific issues. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp. 279–294). Sense Publishers. https://doi.org/10.1007/978-94-6300-749-8_21

Hurd, P. D. (1975). Science, technology and society: New goals for interdisciplinary science teaching. *The Science Teacher, 42*(2), 27–30.

Hynes, M. M. (2012). Middle-school teachers' understanding and teaching of the engineering design process: a look at subject matter and pedagogical content knowledge. *International Journal of Technology and Design Education, 22*, 345–360. https://doi.org/10.1007/s10798-010-9142-4

International Technology and Engineering Educators Association (2019). *ITEEA standards for technological literacy revision project: Background, rationale, and structure*. https://www.iteea.org/File.aspx?id=151454&v=e868d0d8

International Technology and Engineering Educators Association (2020). *Standards for technological and engineering literacy in STEM education* [Pre-Publication Copy]. https://iteea.org/File.aspx?id=175203&v=61c53622

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology*. https://iteea.org/File.aspx?id=42622

Jackson, C., Tank, K. M., Appelgate, M. H., Jurgenson, K., Delaney, A., & Erden, C. (2020). History of integrated STEM curriculum. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 169–183). Routledge. https://doi.org/10.4324/9780429021381-17

JASS. (n.d.). *Problem tree analysis: Problems, causes and consequences.* We-Rise Toolkit. https://werise-toolkit.org/en/system/tdf/pdf/tools/Problem-Tree-Analysis_0.pdf?file=1&force=

Johnson, J. A., Batkie, R., Macalalag, A., Dunphy, J., & Titus, S. (In press). The rise of STEM education: Socioscientific issues and STEM learning. *International Encyclopedia of Education* (4th ed.). Elsevier

Johnson, J., Macalalag, A. Z., Jr., & Dunphy, J. (2020). Incorporating socioscientific issues into a STEM education course: Exploring teacher use of argumentation in SSI and plans for classroom implementation. *Disciplinary and Interdisciplinary Science Education Research, 2*, Article 9. https://doi.org/10.1186/s43031-020-00026-3

Johnson, J., Macalalag, A., Mathers-Lowery, B., & Ialacci, G. (2022). We strive: Initial explorations of STEM teachers' successes and challenges in implementing socioscientific issues. *Pennsylvania Teacher Educator, Fall 2022*.

Jørgensen, U. (2007). Historical accounts of engineering education. In E. Crawley, J. Malmqvist, S. Östlund., & D. Brodeur (Eds.), *Rethinking engineering education: The CDIO approach* (pp. 216–240). Springer. https://doi.org/10.1007/978-0-387-38290-6_10

Kahn, S. (2019). *It's still debatable: Using socioscientific issues to develop scientific literacy, K-5*. NSTA Press.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*, Article 11. https://doi.org/10.1186/s40594-016-0046-z

Kinskey, M., & Zeidler, D. (2021). Elementary preservice teachers' challenges in designing and implementing socioscientific issues-based lessons. *Journal of Science Teacher Education, 32*(3), 350–372. https://doi.org/10.1080/1046560X.2020.1826079

Knight-Bardsley, A., & McNeill, K. L. (2016). Teachers' pedagogical design capacity for scientific argumentation. *Science Education, 100*(4), 645–672. https://doi.org/10.1002/sce.21222

Kokka, K. (2018). Radical STEM teacher activism: Collaborative organizing to sustain social justice pedagogies in STEM fields. *The Journal of Educational Foundations, 31*(1&2), 86–113.

Kokka, K. (2019). Healing-informed social justice mathematics: Promoting students' sociopolitical consciousness and well-being in mathematics class. *Urban Education, 54*(9), 1179–1209. https://doi.org/.org/10.1177/0042085918806947

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*(3), 291–310. https://doi.org/10.1002/sce.1011

Kranzberg, M. (1991). Science-technology-society: It's as simple as xyz! *Theory Into Practice, 30*(4) 234–241. https://doi.org/10.1080/00405849109543507

Ladson-Billings, G. (1995a). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice, 34*(3), 159–165.

Ladson-Billings, G. (1995b). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 456–491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (2009). *The dreamkeepers: Successful teachers of African American children* (2nd ed.). Jossey-Bass.

Layton, D. (1988). Revaluing the T in STS. *International Journal of Science Education, 10*(4), 367–378. https://doi.org/10.1080/0950069880100404

Lee, H. (2016). Conceptualization of an SSI-PCK framework for teaching socioscientific issues (Machine Translated by Google). *Journal of the Korean Association for Science Education, 36*(4), 539–560. https://doi.org/10.14697/jkase.2016.36.4.0539

Lee, H., & Chang, H. (2010). Exploration of experienced science teachers' personal practical knowledge of teaching socioscientific issues (SSI). *Journal of the Korean Association for Science Education, 30*(5), 353–365.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. Sage.

Lindahl, M. G., Folkesson, A.-M., & Zeidler, D. L. (2019). Students' recognition of educational demands in the context of a socioscientific issues curriculum. *Journal of Research in Science Teaching, 56*(9), 1155–1182. https://doi.org/10.1002/tea.21548

Macalalag, A. Z. (2012). *Changes in knowledge of inquiry and practice of lesson design* (Publication No. 3521373) [Doctoral dissertation, Rutgers University]. ProQuest Dissertations Publishing. https://doi.org/10.7282/T3833R0V

Macalalag, A. Z., Jr., Johnson, J., Lai, M. (2020). How do we do this: Learning how to teach socioscientific issues. *Cultural Studies of Education, 15*, 389–413. https://doi.org/10.1007/s11422-019-09944-9

Macalalag, A., Johnson, J., Minken, Z., Mathers-Lowery, B., Liao, E., Marte, M. (2023). Socioscientific issues to promote discussions on social justice: Making STEM concepts accessible and relevant to everyday life experiences of grades 6-12 students. *Hawaii International Conference on Education*, Honolulu, Hawaii, January 3–6, 2023.

Macalalag, A. M., Minken, Z., Feighan, K., & Richardson, M. (2023). Socioscientific issues (SSI): Understanding STEM through integrated contexts in everyday life. *14th International Congress on New Trends in Education*, Aydin, Turkey, September 3–6, 2023.

Macalalag, A. Z., Jr., Minken, Z., & Varma, C. (2023). SSI: Teachers make STEM concepts relevant to their students. *The Eurasia Proceedings of Educational & Social Sciences, 2023, 31*, 119–126.

Madden, P. E., Wong, C., Vera Cruz, A. C., Olle, C. D., & Barnett, M. (2017). Social justice driven STEM learning ($S_{TEM}J$): A curricular framework for teaching STEM in a social justice driven, urban, college access program. *Catalyst: A Social Justice Forum, 7*(1), Article 4.

Magee, P. A., Willey, C., Ceran, E., Price J., & Barrera Cervantes, J. (2020). The affordances and challenges of enacting culturally relevant STEM pedagogy. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of Research on STEM Education* (pp. 300–310). Routledge. https://doi.org/10.4324/9780429021381-28

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Kulwer Academic Publishers.

Malaty, G. (1988). What is wrong with the 'back-to-basics' movement, and what was wrong with the 'new-math' movement. *International Journal of Mathematics Education in Science and Technology, 19*(1), 57–65. https://doi.org/10.1080/0020739880190105

Marshall, C., & Rossman, G. B. (2016). *Designing Qualitative Research* (6th ed.). Sage.

Mateas, V. (2016). Debunking myths about the standards for mathematical practice. *Mathematics Teaching in the Middle School, 22*(2), 92–99. https://doi.org/10.5951/mathteacmiddscho.22.2.0092

McElhaney, K. W., Gane, B. D., DiBello, L. V., Fujii, R., Haugabook Pennock, P., Vaishampayan, G., & Pellegrino J. W. (2017, April 27–May 1). *Designing scoring rubrics to support NGSS-aligned, classroom-based formative assessment* [Paper presentation]. American Educational Research Association Annual Meeting, San Antonio, TX, United States.

McIntosh, P. (1989). White privilege: Unpacking the invisible knapsack. *Peace and Freedom, July/August*, 10–12. https://psychology.umbc.edu/wp-content/uploads/sites/57/2016/10/White-Privilege_McIntosh-1989.pdf

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on k-12 teachers. *Science Education, 97*(6), 936–972. https://doi.org/10.1002/sce.21081

Mensah, F. M. (2009). Confronting assumptions, biases, and stereotypes in preservice teachers' conceptualizations of science teaching through the use of a book club. *Journal of Research in Science Teaching, 46*(9), 1041–1066. https://doi.org/10.1002/tea.20299

Mensah, F. M. (2011). A case for culturally relevant teaching in science education and lessons learned for teacher education. *The Journal of Negro Education, 80*(3), 296–309.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). Jossey-Bass.

Mims, C. (2003). Authentic learning: A practical introduction and guide for implementation. *Meridian: A Middle School Computer Technologies Journal, 6*(1). https://www.researchgate.net/publication/228395999

Minken, Z., & Macalalag, A. (2021) Evolution of STEM Teachers' Pedagogical Content Knowledge through Socioscientific Issues. Paper presented at *International Conference on Science and Technology Education*, October 7-8, Porto, Portugal.

Minken, Z., Macalalag, A. Z., Jr., Clarke, A., Marco-Bujosa, L., & Rulli, C. (2021). Development of teachers' pedagogical content knowledge during lesson planning of socioscientific issues. *International Journal of Technology in Education, 4*(2), 113–165. https://doi.org/10.46328/ijte.50

Minken, Z., Macalalag, A., Feighan, K., Richardson, M., & Ciotoli, G. (2024). Why do we have to learn this? Teachers Make STEM Subjects Relevant to their Students. *Annual Conference of the American Educational Research Association*, Philadelphia, Pennsylvania, April 11-14, 2024.

Minken, Z., Macalalag, A. Z., Jr., & Richardson, G. (2020). Developing teachers' intentions of incorporating socioscientific issues in lesson design. *Pennsylvania Teacher Educator, 19*, 85–96.

Miriti, M. N., Boswer, G., Cid, C. R., & Harris, N. C. (2021). Overcoming blind spots to promote environmental justice research. *Trends in Ecology & Evolution, 35*(4), 269–273. https://doi.org/10.1016/j.tree.2020.12.011

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108(*6), 1017–1054.

Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Nickels, M. (2020). Moving toward an equity-based approach for STEM literacy. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 29–38). https://doi.org/10.4324/9780429021381-4

Morales-Doyle, D. (2015). *Science education as catalyst for social change? Justice-centered pedagogy in secondary chemistry* [Doctoral Dissertation, University of Illinois at Chicago]. https://hdl.handle.net/10027/19765

Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education, 101*(6), 1034–1060. https://doi.org/10.1002/sce.21305

Morales-Doyle, D. (2020). The aspirin unit: Confronting a hostile political context through chemistry curriculum. *Cultural Studies of Science Education, 15*, 639–657. https://doi.org/10.1007/s11422-020-09993-5

National Academies of Sciences, Engineering, and Medicine [NASEM]. (2019). *Science and engineering for grades 6-12: Investigation and design at the center.* The National Academies Press. https://doi.org/10.17226/25216

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Author.

National Science Teachers Association. (1982). *Science-technology-society: Science education for the 1980's.* Position Paper.

National Research Council. (1989). *Everybody Counts: A report to the nation on the future of mathematics education*. The National Academies Press. https://doi.org/10.17226/1199

National Research Council. (1996). *National science education standards.* The National Academies Press. https://doi.org/10.17226/4962

National Research Council. (1999). *How people learn: Bridging research and practice*. The National Academies Press. https://doi.org/10.17226/9457

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. The National Academies Press. https://doi.org/10.17226/9596

National Research Council. (2006). *America's lab report: Investigations in high school science.* The National Academies Press. https://doi.org/10.17226/11311

National Research Council. (2009). *Engineering in k-12 education: Understanding the status and improving the prospects*. The National Academies Press. https://doi.org/10.17226/12635

National Research Council. (2010). *Standards for k-12 engineering education?* The National Academies Press. https://doi.org/10.17226/12990

National Research Council. (2012). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. https://doi.org/10.17226/13165

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press. https://doi.org/10.17226/18290

North, C. E. (2006). More than words? Delving in to the substantive meaning(s) of "social justice" in education. *Review of Educational Research, 76*(4), 507–535. https://doi.org/10.3102/00346543076004507

Olayemi, M., & DeBoer, J. (2021, January 24–28). Enacting culturally relevant pedagogy for underrepresented minorities in STEM classrooms: Challenges and opportunities [Paper presentation]. *2021 Collaborative Network for Engineering and Computing Diversity Conference*, Virtual. https://peer.asee.org/36084

Owens, D. C., & Sadler, T. D. (2020). Socio-scientific issues as contexts for the development of STEM literacy. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM educatio*n (pp. 210–222). Routledge. https://doi.org/10.4324/9780429021381-20

Porter, T., West., M. E., Kajfez, R. L., Malone, K. L., & Irving, K. E. (2019). The effect of teacher professional development on implementing engineering in elementary schools. *Journal of Pre-College Engineering Education Research, 9*(2), Article 5. https://doi.org/10.7771/2157-9288.1246

Presley, M. L., Sickel, A. J., Muslu, N., Merle-Johnson, D., Witzig, S. B., Izci, K., & Sadler, T. D. (2013). A framework for socio-scientific issues based education. *Science Educator, 22*(1), 26–32.

Pruitt, S. L. (2014). The next generation science standards: The features and challenges. *Journal of Science Teacher Education, 25*, 145–156. https://doi.org/10.1007/s10972-014-9385-0

Pulcinella, M. (2022, April 1). Philly's plastic bag ban is now fully in effect -- enforcement included. *WHYY*. https://whyy.org/articles/philly-plastic-bag-ban-enforcement-exemptions-2022/

Qian, Y., Hambrusch, S., Yadav, A., Gretter, S., & Li, Y. (2020). Teachers' perceptions of student misconceptions in introductory programming. *Journal of Educational Computing, 58*(2), 364–397. https://doi.org/10.1177/0735633119845413

Qian, Y., & Lehman, J. D. (2019). Using targeted feedback to address common student misconceptions in introductory programming: A data-driven approach. *Sage Open, 9*(4), 1–20. https://doi.org/10.1177/2158244019885136

Rodriguez, A. J. (1998). Strategies for counterresistance: Toward sociotransformative constructivism and learning to teach science for diversity and for understanding. *Journal of Research in Science Teaching, 35*(6), 589–622. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6<589::AID-TEA2>3.0.CO;2-I

Rodriguez, A. J., & Berryman, C. (2002). Using sociotransformative constructivism to teach for understanding in diverse classrooms: A beginning teachers' journey. *American Education Research Journal, 39*(4), 1017–1045. https://doi.org/10.3102/000283120390041017

Sadler, T. D. (2004). Moral sensitivity and its contribution to the resolution of socio-scientific issues. *Journal of Moral Education, 33*(3), 339–358. https://doi.org/10.1080/0305724042000733091

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*, 371–391. https://doi.org/10.1007/s11165-006-9030-9

Sadler, T. D., Friedrichsen, P., & Zangori, L. (2019). A framework for teaching for socio-scientific issue and model based learning (SIMBL). *Revista Educação e Fronteiras On-Line, 9*(25), 8–26. https://doi.org/10.30612/eduf.v9i25.11006

Sadler, T. D., & Zeidler, D. L. (2005a). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42*(1), 112–138. https://doi.org/10.1002/tea.20042

Sadler, T. D., & Zeidler, D. L. (2005b). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89*, 71–93. https://doi.org/10.1002/sce.20023

Sarwadi, H. R. H., & Sharill, M. (2014). Understanding students' mathematical errors and misconceptions: The cases of year 11 repeating students. *Mathematics Education Trends and Research, 2014*, 1–10.

Saunders, K., & Rennie, L. J. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education, 43*, 253–274. https://doi.org/10.1007/s11165-011-9248-z

Schneider, R. M. (2015). Pedagogical content knowledge reconsidered: A teacher educator's perspective. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 162–177). Routledge.

Shapiro, L. J., & Kraus, R. V. (2022). The NGSS and the historical direction of science education reform. *Science Educator, 28*(2), 63–74.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. https://doi.org/10.2307/1175860

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Shulman, L. S. (2015). PCK: Its genesis and exodus. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 3–13). Routledge.

Shymansky, J. A., Kyle, W. C., Jr., & Alport, J. M. (1983). The effects of new science curricula on student performance. *Journal of Research in Science Teaching, 20*(5), 387–404. https://doi.org/10.1002/tea.3660200504

Sloan, K., Allen, A., Bass, K. M., & Milligan-Mattes, E. (2018). Evaluation of PCK in STEM residency programs: Challenges and opportunities. In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in STEM: Research into practice* (pp. 157–175). Springer. https://doi.org/10.1007/978-3-319-97475-0_9

Smith, P. S., & Banilower, E. R. (2015). Assessing PCK: A new application of the uncertainty principle. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 88–103). Routledge.

Smith, P. S., Plumley, C. L., Hayes, M. L., & Esch, R. K. (2018). Personal and canonical PCK: A synergistic relationship? In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in STEM: Research into practice* (pp. 49–66). Springer. https://doi.org/10.1007/978-3-319-97475-0_3

Stake, R. E. (2010). *Qualitative research: Studying how things work*. The Guilford Press.

Stanic, G. M. A., & Kilpatrick, J. (1992). Chapter 1 Mathematics curriculum reform in the United States: A historical perspective. *International Journal of Educational Research, 17*(5), 407–417. https://doi.org/10.1016/S0883-0355(05)80002-3

Sun, Y., & Strobel, J. (2014). From knowing-about to knowing-to: Development of engineering pedagogical content knowledge by elementary teachers through perceived learning and implementing difficulties. *American Journal of Engineering Education, 5*(1), 41–60. https://doi.org/10.19030/ajee.v5i1.8610

Tan, L. (2009). The 5 E's of emancipatory pedagogy: The rehumanizing approach to teaching and learning with inner-city youth. In W. Ayers, T. Quinn, & D. Stovall (Eds.), *Handbook of social justice in education* (pp. 485–496). Routledge.

Tanner, L. N. (1997). *Dewey's laboratory school: Lessons for today*. Teachers College press.

Thompson, R. (2018). Pedagogical content knowledge in a mathematics adolescent education master of arts program: A case study. In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in STEM: Research into practice* (pp. 145–156). Springer. https://doi.org/10.1007/978-3-319-97475-0_8

Tobin, K. (2002). Beyond the bold rhetoric of reform: (Re)learning to teach science appropriately. *Counterpoints, 210*, 125–150.

Tsurusaki, B. K., Calabrese Barton, A., Tan, E., Koch, P., & Contento, I. (2013). Using transformative boundary objects to create critical engagement in science: A case study. *Science Education, 97*(1), 1–31. https://doi.org/10.1002/sce.21037

Turnuklu, E. B., & Yesildere, S. Y. (2007). The pedagogical content knowledge in mathematics: Pre-service primary mathematics teachers' perspectives in Turkey. *Issues in the Undergraduate Mathematics Preparation of School Teachers, 1*, 1–13.

Varelas, M., Morales-Doyle, D., Raza, S., Segura, D., Canales, K., & Mitchener, C. (2018). Community organizations' programming and the development of community science teachers. *Science Teacher Education, 102*(1), 60–84. https://doi.org/10.1002/sce.21321

Watkins, J., & Manz, E. (2022). Characterizing pedagogical decision points in sense-making conversations motivated by scientific uncertainty. *Science Education, 106*(6), 1408–1441. https://doi.org/10.1002/sce.21747

Wilson, C. D., Stuhlsatz, M., Hvidsten, C., & Gardner, A. (2018). Analysis of practice and teacher PCK: Inferences from professional development research. In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in STEM: Research into practice* (pp. 3–16). Springer. https://doi.org/10.1007/978-3-319-97475-0_1

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Young, I. (1990). *Justice and the politics of difference*. Princeton University Press.

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research, and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 697–726). Routledge. https://doi.org/10.4324/9780203097267-45

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education, 11*, 11–26. https://doi.org/10.1007/s11422-014-9578-z

Zeidler, D. L., Applebaoum, S. M., & Sadler, T. D. (2011). Enacting a socioscientific issues classroom: transformative transformations. In T. D. Sadler (Ed.), Socio-scientific issues in science classrooms: *Teaching, learning and research* (pp. 277–306). Springer. https://doi.org/10.1007/978-94-007-1159-4_16

Zeidler, D. L., & Kahn, S. (2014). *It's debatable! Using socioscientific issues to develop scientific literacy, k-12*. NSTA Press.

Zeidler, D. L., & Keefer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education: Philosophical, psychological and pedagogical considerations. In D. L. Zeidler (ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 7–38).

Zeidler, D. L., & Sadler, T. D. (2008). Social and ethical issues in science education: A prelude to action. *Science & Education, 17*, 799–803. https://doi.org/10.1007/s11191-007-9130-6

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for teaching socioscientific issues education. *Science Education, 89*(3), 357–377. https://doi.org/10.1002/sce.20048

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86*(3), 343–367. https://doi.org/10.1002/sce.10025

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics, 112*(1), 12–19. https://doi.org/10.1111/j.1949-8594.2012.00101.x

Appendix A: Data Sources

Data Source 1: J-STEM End-of-Year Interview

Semi-Structured Interview Questions (30-60 min)

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

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

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

2. From the beginning of the project to now, in what ways have your teaching practices for integrating STEM teaching with social justice goals evolved?

3. In what ways, if any, do your students become involved in (civic engagement) in their community?
   a. What have you done to prepare your students?
   b. Thinking about last year and this year, in what ways do you think your teaching practices change in fostering civic engagement?
   c. Explain why you made those pedagogical decisions.

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

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

      - As a teacher, describe what your students are struggling to do?

      - What are you going to do to help your students evaluate multiple perspectives?

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

- As a teacher, can you please describe the scientific phenomenon that students do not understand?

- Describe activities your students can investigate regarding this phenomenon.

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

- There are multiple articles that show dining out and its effects on economy and physical and mental health. As a teacher, how will you guide your students to scientifically evaluate and question information from different sources?

5. How did you support students' SSI knowledge/ability across the 3 elements of SSI (social, scientific, discursive) in your instruction and to give examples?
    a. Based on your unit, how would you modify it next time to better address these goals?

6. Is there anything else that I didn't ask, but you feel would be important to talk about?

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

Data Source 2: Reflective Interview on SJSP Unit of Study
Adapted from Grossman (1990)

Semi-Structured Interview Questions (30-60 min)

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

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

1. Tell me about your unit on __________.
   a. How did you introduce it?
   b. What were your goals for the unit?
   c. What kinds of things did you take into consideration in planning the unit?
   d. Can you tell me about some of the discussions/lessons?
   e. How long did the unit take?
   f. How did you leverage your students' interests in choosing the SSI for this unit?
2. Tell me about the students in the class. [probe for number of students, heterogeneity or homogeneity of class, student backgrounds and interests]
   a. What are some of the things/issues that are high-interest to your students?
   b. What activities do your students tend to find engaging?
   c. What are some issues of social (in)justice that your students talk about?
3. How did you draw your students' attention to issues of injustice inherent in your SSI? [probe for instructional strategies]
4. How did you facilitate student discussion around unpacking the various complexities of the SSI?
5. What were some of the issues of injustice that surfaced during the unit of study?
   a. How did you facilitate student exploration of this injustice?
   b. What teaching strategies did you employ?
   c. How did students' cultural backgrounds play a role in unpacking these issues?
   d. How did your cultural background play a role in unpacking these issues?
6. Did you have any final paper, test, project, or culminating activity associated with the unit?
   a. What was it like?
   b. Why did you choose this activity in particular?
   c. How, if at all, did this culminating activity extend student learning beyond the walls of the classroom?
7. Tell me what you thought the students got out of the unit.

8. Tell me how you thought the unit went.
    a. How would you change the unit if you were to teach it again?
9. Think back to a different group of students you taught, perhaps at a different school.
    a. What was different about this group of students? [probe for number of students, heterogeneity or homogeneity of class, student backgrounds and interests]
    b. How might you change the unit if you were teaching this group of students?
10. Is there anything else that I didn't ask, but you feel would be important to talk about?

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

Data Source 3: SJSP Unit of Study

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 Lesson Description:</td></tr>
<tr><td colspan="3">Description and Explanation of SocioScientific Issues (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">Standards for Mathematical Content:

Standards for Mathematical Practice:</td></tr>
</table>

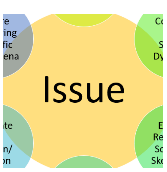
Students' Prior Conceptions:

Sociotransformative constructivism (sTc):

1. Explain how this lesson provides students with the opportunity to choose and connect with a topic of local importance.
   a. How is the issue important to students?
   b. How is the issue evident in students' locale/community?
   c. Which student funds of knowledge are tapped in addressing the issue?
   d. Will the students have opportunities for authentic change in their community?
2. How do students' cultural background, socioeconomic status, belief systems, values, education, and skills influence what you consider is important to teach/learn in this lesson?

LESSON PLAN

ENGAGE: Establish relevance - help learner determine need of learning new concepts

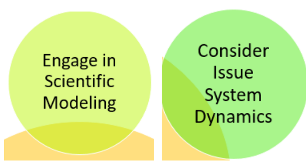


sTc: "Why am I learning about this topic?"

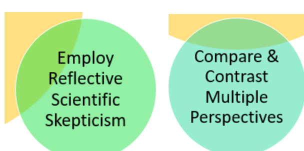
EXPLORE: Engage students in the content - help learner understand concepts, process/procedures, facts or principles

sTc: "Why am I learning these concepts in this way?"

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

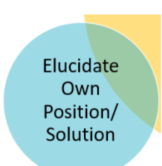


ELABORATE: Construct new learning - help learner apply prior learning and acquire new



sTc: "What control [voice] do I have in how to proceed?"

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



sTc: "By what other method(s) can I learn this subject matter best?"

Elaborate Further / Reflect: Enrichment:

Data Source 4: SJSP Classroom Artifact & Reflection #1

Purpose: For teachers to reflect on students' thinking of SSI and social justice using student-generated artifacts.

Guidelines:

1. Select student artifacts (e.g. assignments, projects, essays, videos, etc.) that you think exemplify their learning of SSI and stance on social justice.

2. Highlight and explain the components of SSI that you think the students learned. Please be specific.

3. What components of SSI are challenging for your students? Explain your answer.

4. Provide examples that exemplify their stance on social justice. Explain your rationale.

5. Describe what you would do next to help your students grow on their knowledge and practices on SSI and social justice.

Data Source 5: SJSP Classroom Artifact & Reflection #2

Purpose: For teachers to reflect on students' thinking of SSI and social justice using student-generated artifacts.

Guidelines:

1. Select student artifacts (e.g. assignments, projects, essays, videos, etc.) that you think exemplify how students extended their learning of SSI and stance on social justice beyond the walls of the classroom.

2. Highlight and explain the ways in which student learning extended beyond the walls of the classroom. Please be specific.

3. What components of SSI are challenging for your students? Explain your answer.

4. Provide examples that exemplify their stance on social justice. Explain your rationale.

5. Describe what you would do next to help your students grow on their knowledge and practices on SSI and social justice.

Appendix B: SJSP Theory-Generated Coding Guide

Domain 0: Authentic Activity
Involves inquiry-based, hands-on, minds-on activities that are also socio-culturally relevant and tied to the everyday life and interests of the learner.
Domain 1: Scientific Aspects
1) Explore and explain the underlying scientific phenomena and/or concepts in mathematics Think of opportunities for students to explore and explain the scientific phenomenon or concepts in mathematics associated with the focal issue. This anchor phenomenon must be relevant to students' everyday experiences, observable, complex, have associated data, text and images, and part of the school's curriculum (Sadler et al., 2019).
2) Engage in STEM modeling Allow students to engage in scientific modeling and reasoning through development, use, evaluation, and revision of STEM models that are connected to the SSI discussion. Models are used to convey and explain information through investigations. Example classroom models include: conceptual (e.g. drawings and sketches), mathematical (e.g. graphs and equations), physical (e.g. stream table), engineering (e.g. designs and physical model of a bridge), and computer-oriented model (e.g. online simulation). (Macalalag, 2012)
Domain 2: Social Aspects
3) Exploration of SSI The socioscientific issues are "local and global controversies related to almost any science or mathematics topics. As you explore topics, consider students' interests and select topics with relevance to their lives and the [school's] curriculum" (Zeidler & Kahn, 2014, p. 31).
4) Consider issue system dynamics Ask students to consider a system associated with their SSI. The system may include interactions of humans with nature as well as social components such as political, cultural, economic, ethical, health, nature, equity, and religious considerations.
5) Compare and contrast multiple perspectives Ask students to obtain and evaluate information from a range of stakeholders such as environmental activists, politicians, political groups, researchers, scientists, religious organizations, and media.
Domain 3: Problematization

6) Employ reflective scientific skepticism Teach students to consider the following questions while reviewing their data and sources of information (Sadler et al., 2019): What biases could affect the presentation of information? Who is the author or organization disseminating the information? What is the purpose and/or methodology for obtaining information? What expertise and/or relevant experience does the author have? Who is disadvantaged/advantaged with respect to the SSI?
7) Reflexivity Providing avenues to elicit and voice with respect to one's cultural background, moral and ethical stance, socioeconomic status, belief systems, values, education, and skills influence what we consider is important to teach/learn (Calabrese, 2003 in Rodriguez, A.J., Morrison, D., 2019; Zeidler, 2014).
8) Dialogic Conversation Provides opportunities for students to voice their own reasons (emotional tone, ideological, and conceptual positions) the speaker chooses in a specific context.
Domain 4: Agency & Action
9) 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.
10) Metacognition Provides opportunities for students to use their learning experiences to transform (actions) themselves and others.

Appendix C: Recruitment Email Communication Script

Hello _________________,

My name is Zachary Minken and I am a doctoral student at Arcadia University conducting a dissertation research study exploring the ways in which teachers in the J-STEM program express and adapt their knowledge of teaching to teach STEM for social justice. This study has been approved by Arcadia's IRB. Participation in this study will involve participation in two research interviews in which you will reflect on different aspects of your pedagogy related to the unit of study you developed as part of the J-STEM program, as well as granting me access to review interview transcripts and artifact submissions/reflections you have already submitted to J-STEM through your participation in the J-STEM research project.

If you would like to participate in this study, please read, sign, and return the attached permission slip.

If you have any questions about this study, please reach out either to me or to Augusto Macalalag (macalalaga@arcadia.edu), who is supervising this dissertation research.

Thank you,

Zachary Minken
Doctoral Candidate
Arcadia University
450 S. Easton Road
Glenside, PA 19038

Appendix D: Consent Form

Consent for Participation in a Human Research Study

Teacher Consent Form

Title of research study: Teaching STEM for Social Justice: An Exploration and Analysis of Teachers' Pedagogical Content Knowledge

IRB #: Arcadia IRB-#######-#

Investigators: Zachary Minken, Arcadia University

Key Information: This section is intended to provide key information to assist in your decision on whether to participate in this research study. This study involves research and is voluntary. You can stop at any time without penalty.

This research study will explore and analyze the ways in which teacher knowledge and beliefs was expressed and adapted through the development of a unit of study centering around STEM and social justice, created as part of your participation in the J-STEM program. Your participation in this project will require approximately two hours of your time over two 1-hour sessions. Participation in the research is completely voluntary. You will also be asked to participation in two research interviews in which you will reflect on different aspects of your pedagogy related to the unit of study you developed as part of the J-STEM program, as well as granting me access to review interview transcripts and artifact submissions/reflections you have already submitted to J-STEM through your participation in the J-STEM research project. Research activities you will be asked to participate in will take up no more than two hours of your time, and will be completed in two 1-hour sessions scheduled at a time and location (e.g., over Zoom) of your convenience.

There are minimal risks associated with participating in this research study. Participants might experience discomfort when being interviewed or observed. Participants may be uncomfortable sharing their unit plans. This study may include risks that are unknown at this time.

There is no direct benefit derived from participation in this research study.

This Study: This research has been reviewed and approved by the Arcadia University and Villanova University Institutional Review Board ("IRB"). You may talk to either IRB office at the contact information below if you have any questions or concerns you'd like to discuss with someone independent of the research or if you feel you have been harmed in any way by the research.

- Arcadia IRB email: IRB_IACUC@arcadia.edu
- Arcadia IRB phone: 267-620-4111

Reforms in Science, Technology, Engineering, and Mathematics education over the past several decades have resulted in a somewhat steady pressure to infuse personal, social, and cultural relevance into STEM education. This emphasis on relevance eventually resulted in a push for social justice in education as a means to both engage learners and to develop students' moral and ethical reasoning abilities in hopes that this would lead to a more just world. Amidst rising concerns for relevant and equitable curricula, SSI can be seen as an avenue to provide STEM teaching through a more justice-centered approach. However, engaging in social justice pedagogies in general is not always easy for teachers, and often underexplored for STEM teachers in particular.

This research study is designed to explore and analyze the (re)development of teachers' knowledge and beliefs relating to STEM and social justice through the development of an SJSP unit of study created during a professional development (PD) program centered around SJSP. SJSP organizes instruction around an authentic, organizing SSI, and is used to embed STEM content within sociocultural contexts relevant to students' lives. Through exploration of this SSI, the teacher is able to reframe the SSI as related to issues of injustice through problematization, and develop students' agency and move them to act in order to help resolve the issues of injustice revealed by the SSI. Through qualitative methodology, this research plan is designed to reveal elements of teachers' knowledge and beliefs that enabled and supported them in teaching STEM for social justice.

I invite you to take part in this research study because you are participating in the SJSP professional development programming.

In this study you will be invited to participate in the following research activities intended to assess the ways in which you expressed and adapted your beliefs and instructional practices through the (re)development of a unit of study teaching STEM for social justice. Note that research activities already completed through your participation in the USTRIVE program are marked with an asterisk (*).

- *Reflective Interview on J-STEM Unit of Study*. Interviews will take place in-person or remotely at a time and location that is convenient for the teacher. Interviews will be audio-recorded and transcribed. This interview is estimated to take approximately 1 hour.

- *Stimulated Recall Interview Using J-STEM Unit of Study*. Interviews will take place in-person or remotely at a time and location that is convenient for the teacher. Interviews will be audio-recorded and transcribed. This interview is estimated to take approximately 1 hour.

- *J-STEM End of Year Interview**. Individual end-of-year interviews from a subset of teachers. Interviews will take place in-person or remotely at a time and location that is convenient for the teacher. Interviews will be audio-recorded and transcribed.This data was previously collected by J-STEM research staff between March and June of 2022.

- *Teacher developed unit plans**. You already developed these unit plans through your participation in the J-STEM program. This data was previously collected by J-STEM research staff in May 2022 and May 2023

- *Select classroom artifacts** (e.g. student assignment, project, verbal and written explanations). This data will be de-identified by the teacher and will reflect their instructional practice. This data was previously collected by J-STEM research staff in May 2022 and May 2023.

Your participation in research is completely voluntary. You can decide to participate or not to participate and can leave the study at any time with no penalty to you, and you will not lose any benefits to which you are otherwise entitled. You can leave the research at any time it will not be held against you. If you inform me of your withdrawal at any point during the study, you will be free to leave, and all data gathered up until that point will be deleted and not included in data analysis upon your request.

Risks: By agreeing to be part of this study, you may be exposed to the following risks. Participants might experience discomfort when being interviewed or observed. Participants may be uncomfortable sharing their unit plans. This study may include risks that are unknown at this time.

If participants should experience discomfort for any reason during the interviews, a) the participant will be permitted to not answer the question; b) the facilitator will immediately address the participant's concerns and resume the interview if the participant agrees; c) the participant will be advised that s/he may withdraw from the study.

If participants should experience discomfort with sharing their instructional practice, either in sharing unit plans or other lesson artifacts, the researcher will immediately address the participant's concerns and only continue with data collection if the participant agrees and/or the participant will be advised that s/he may withdraw from the study.

Although unanticipated, it is also possible that there are risks to you that I as a researcher cannot foresee.

Benefits: There is no direct benefit to participating in this dissertation research study.

Confidentiality: Efforts will be made to limit the use and disclosure of your personal information, including research study records, to people who have a need to review this information. I cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization.

All data collected will be kept confidential. Every effort will be made to prevent the identity of an individual from being revealed. Names will be replaced by codes to ensure confidentiality. Names of individuals and schools will not be reported in any public (non-internal) documents. Teacher data will be reported in aggregate and all quotes will be attributed to a subject with an anonymized codes as a unique identifier (e.g., participant 12) or as part of a group (e.g., several participants responded). No subject data will be identifiable individually in any reports or other documents. I will be responsible for managing research data collected and ensuring that it is uploaded to a secure central data repository (Google Drive) to be controlled by Arcadia. Data will be kept for three years after the completion of the study to allow for analysis. I will physically destroy and electronically shred the data after this date. I am responsible for ensuring that the data is well-scrubbed, any identification removed and replaced with codes, and in good form before data is turned over to any scores/coders for analyses. Respondent names will never be associated with project data to maintain confidentiality. Access to raw data will be restricted to myself and my dissertation committee supervising this research.

I will provide you a copy of this form for your records.

Signature Block for Capable Adult

Your signature documents your voluntary consent to take part in this research. You affirm you are 18 or older.

Signature of subject

Date

Printed name of subject

Signature of person obtaining consent

Date

Printed name of person obtaining consent