Socioscientific Modeling as an Approach Toward Justice-Centered Science Pedagogy

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Introduction

A Framework for K-12 Science Education (National Research Council [NRC], 2012; hereafter shortened to the *Framework*), codified in the Next Generation Science Standards (NGSS; Next Generation Science Standards Lead States [NGSS], 2013) redefined how K-12 science education can best prepare students to be college and career ready by the end of high school through a focus on science literacy cultivated through disciplinary practices in the United States (NGSS, 2013). Similar commitments have been made internationally including the National Curriculum for Science in England with an emphasis on students communicating scientific ideas effectively (Ryder & Banner, 2011), and The Australian Curriculum which provides a framework for developing students skills (Treagust et al., 2015). These commitments prioritize students figuring out and developing conceptual understanding of natural phenomena through engaging in epistemic practices such as modeling (Berland, 2016; Duschl, 2008). The research these reforms are based on emphasize students participating in knowledge-building processes through disciplinary work. In most instances however, science learning environments do not often make these types of knowledge-building opportunities available to students from historically minoritized communities because traditional pedagogical orientations and instructional approaches fail to appreciate the diverse repertoires of cultural practices, knowledge, experiences, and motivations students bring with them to the classroom (Bang et al., 2012; Rosebery et al., 2010).

A limitation of the standards is that they only operate as guidelines; therefore, implementation is dependent on school systems and educators tailoring curricula and instruction to meet these reform-oriented approaches for their local context. Unfortunately, these documents fail to provide teachers with resources to bring in the dimensions of science learning that appeal to the means and ends students identify as important to their science education. For example, Garibay (2015) found that historically minoritized students report caring more about science when it is used as a tool for equity, social justice, and helping others. Therefore, a reform-oriented approach should empower students to critique and change the status quo by drawing on their community knowledge and experiences as powerful resources (Morales-Doyle, 2018). Traditional approaches to science instruction, however, tend to maintain restrictive conceptions about what counts as science learning and for what purpose, leaving many students feeling disconnected from the discipline (Aikenhead et al., 2006; Lipman, 2004).

To make science learning environments equitable and accessible to all learners, Morales-Doyle (2017) proposes justice-centered science pedagogy (JCSP) as a framework for science instruction. Drawing on Ladson-Billings' (1995) culturally relevant pedagogy, JCSP calls for students being held to high academic achievement standards and being positioned as producers of knowledge and culture while grappling with issues with direct social justice implications. The challenge of this pedagogical approach is that even teachers who embrace critical pedagogies struggle to incorporate social dimensions of science into their instruction (Bossér et al., 2015; Ekborg et al., 2013; Friedrichsen et al., 2021; Gayford, 2002; Lazarowitz & Bloch, 2005; Lee et al., 2006). Therefore, teachers need additional, discrete instructional strategies that introduce social dimensions of science in ways they feel confident navigating.

In this article we position JCSP as one approach to bridging the gap between students' lives and science content, but we recognize that there is a discontinuity between theory and practice. Therefore, we ask *how does systems modeling, a specific type of socioscientific model, support justice-centered science content?*

We introduce socioscientific modeling as a strategy that privileges equity and access to science practices, which build on the pedagogical foundations laid out by JCSP and remains aligned to the goals of the *Framework*. By offering a resource for students to contextualize science content in relation to their experiences and issues that are important to them, students unpack complex causal relationships while considering the full impact of these issues. In this article we introduce socioscientific modeling as an instructional strategy that aligns with the goals of justice-centered science pedagogy. Following a review of relevant literature, we present emerging evidence from student use of socioscientific modeling for JCSP and end with recommendations for the field.

Theoretical Framing

Justice Centered Science Pedagogy

In response to calls for K-12 science learning to be a space for challenging inequality, Morales-Doyle (2017) advanced justice-centered science pedagogy (JCSP) as a framework that prioritizes social transformation in science instruction. Using principles of culturally relevant pedagogy (CRP; Ladson-Billings, 1995) and social transformation (Freire, 1968, 2018), justice-centered science pedagogy (JCSP) encompasses curriculum, teaching practices, and classroom structures as a way to equip youth to create changes they wish to see in society (Morales-Doyle, 2017, 2018). Scrutinizing science instruction through a critical lens reveals that the current system and pedagogies are often disconnected from students' lives and perpetuate structures that systematically deny visibility, resources, and opportunities to underrepresented minority students (URM; Aikenhead, 2006; Akom et al., 2013; McGee & Bentley, 2017). This critical justice stance for science pedagogies is scarce in current science education literature (Calabrese Barton et al., 2020). Therefore, to fully appreciate and add to the limited research theorizing social justice in science education, one must understand culturally relevant pedagogy (CRP) and how JCSP aligns with the framework Ladson-Billings (1995) offered decades ago (Brown B.A., et al., 2019; Calabrese Barton et al., 2020; Rodriguez, 2015).

Critical Pedagogies

CRP is a way of teaching that uses academic content and the learning process to empower students to challenge social inequity (Ladson-Billings, 2000; Mensha, 2013). CRP goes beyond disciplinary facts and concepts to empower students to critique and apply knowledge and deconstruct social inequality through three principles: : (a) academic success, (b) cultural competence, and (c) critical consciousness (Ladson-Billings, 1995). Students must demonstrate academic competence through developing their academic skills. For students to experience academic competence, educators must value the skills and abilities students naturally bring to the classroom (Ladson-Billings, 1995, 1999, 2006). JCSP positions interesting, relevant issues as a persuasive tool in getting learners to find value in their academic success (Dos Santos, 2009; Morales-Doyle, 2017). The second proposition, students developing and maintaining their cultural competence, involves respecting the values, attitudes, and beliefs of one's personal culture and understanding how that culture interacts with society. Cultural competence is supported when students' home and community culture and traditions are valued through the curriculum such as when presenting issues students care about that are of particular importance to their communities or lives (Underwood & Mensha, 2018). In this way, teachers can use students' cultures as a vehicle for student engagement and learning. Lastly, developing critical consciousness involves students moving beyond the individualistic focus of the first two tenets and developing sociopolitical consciousness that allows them to critique the cultural norms, values, and systems that produce and maintain social inequities (Ladson-Billings, 1995).

Teachers can foster critical consciousness when considering potential solutions to a community problem by challenging students to consider multiple perspectives, investigate the many factors that have contributed to the problem, and take action in the real world to solve this problem.

Cultivating critical consciousness is particularly difficult for science teachers because it brings in sociopolitical components of society that are often omitted from traditional science texts and curricula (Calabrese Barton et al., 2020; Dimick, 2016; Freire & Macedo, 1987). Teachers that tend to shy away from the critical components of science teaching and learning report struggling to incorporate social dimensions of science into their practice (Ekborg et al., 2013; Friedrichsen et al., 2021; Gayford, 2002; Lazarowitz & Bloch, 2005; Lee et al., 2006). For CRP to be fully operationalized, it is important that all three principles are acknowledged and implemented in the classroom, which entails considering how to support teachers in bringing criticality to their classrooms.

JCSP as a Critical Pedagogy

JCSP positions youth as transformative intellectuals poised to see and leverage science as a "catalyst" for change (Morales-Doyle, 2017). Figure 1 is from Morales-Doyle (2017) showcasing JCSP as a catalyst for social change.

Figure 1: Justice-Centered Science Pedagogy with Socioscientific Modeling

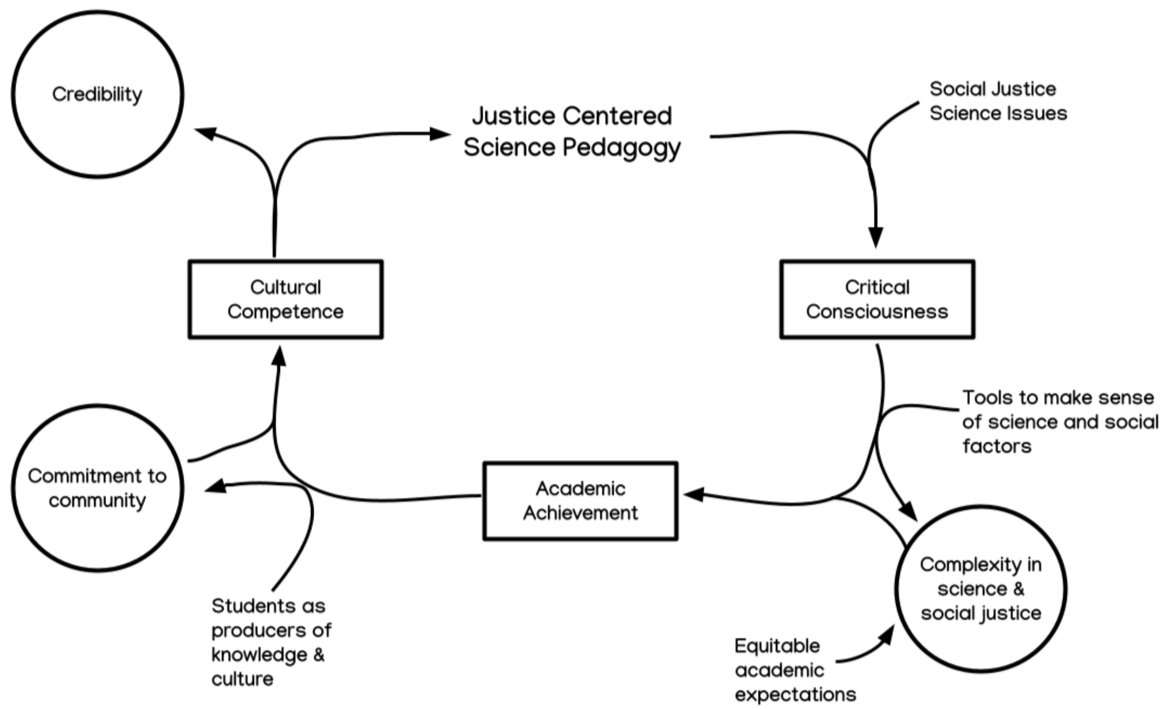


Figure 1 shows how JCSP builds on the tenets of CRP (in rectangles) by adding four pedagogical components (in boldface). The first component, using a social justice science issue as a curricular focus, prompts students to examine issues that are complex, often controversial, and have both science and social components. These types of issues are commonly called socioscientific issues. Morales-Doyle goes beyond previous socioscientific issues frameworks by emphasizing the need for these issues to be of personal and communal importance by appealing to students culturally-rooted interests. This approach is a departure from previous SSI frameworks (Zeidler et al., 2005) in that the problems being posed are rooted in social inequality and cannot be understood without addressing oppression. Morales-Doyle (2017) calls these particular SSI problems *social justice science issues* (SJSI). By bringing the "outside world" into the classroom, JCSP erodes barriers that inhibit students' ability to engage with relevant contexts (Davis & Schaeffer, 2019, p.369; Trinidad, 2011). We add the second component to the diagram, tools to make sense of science and social factors. Students need these tools to engage in sophisticated sensemaking. The third component, maintaining equitable academic expectations, holds teachers accountable to the belief that students can understand and develop a robust understanding of SJSI (Brown, J.C., 2017; Brown B.A., et al., 2019). This understanding should not be limited by standardized tests, but rather explored in students' willingness to wrestle with complex issues and apply science content in usable ways (Laugher and Adams, 2012). Lastly, JCSP involves positioning and acknowledging students as producers of knowledge and culture. In doing so students have opportunities to be experts in the field. Alongside learning canonical science concepts, students strengthen their cultural competence as their histories, community knowledge, and family traditions are treated as meaningful contributions.

JCSP also calls attention to what students get out of JCSP-based instruction (in circles). When treated as "transformative intellectuals" students "[exhibit] complex thinking about SJSI, [cultivate] commitment to their cultures and communities, and [earn] credibility as members of a marginalized community who are developing scientific expertise while they also develop an appreciation for its limits as one way of knowing" (p. 1054). When empowered to construct and use scientific knowledge in relevant contexts, students draw connections between scientific knowledge and transformative action, thus building their belief in their ability to enact change (Dimmick, 2012; Brown B.A., et al., 2019).

In advancing a pedagogical model that leverages principles of Ladson-Billings culturally relevant teaching (1995) and Freire's social transformation (Freire, 1968, 2018), privileged forms of science are problematized, and learning is situated within the context of larger justice movements. JCSP leverages students' knowledge to support agency in identifying, critiquing, and contending with the societal problems they find important.

Funds of Knowledge

Funds of knowledge are historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual wellbeing (Moll & Greenberg, 1990). Initial analysis of the concept (Moll et al., 1992) was undertaken to support K12 educators in adapting classroom teaching and curriculum to students' unique contexts (Denton & Borrego, 2021). Utilization of students' funds of knowledge is a specific aspect of culturally relevant teaching practices which affirm students' identities by positioning them as experts within their own experiences; teaching 'to and through' their experiences (Ladson-Billings, 2009). By teaching 'to and through' students' experiences educators to view their students' unique cultural experiences through an asset versus deficit-based lens.

This is especially important in science education. Dominant discourses have painted a narrow view of what experiences are worthwhile and valid within the disciplinary community. When teachers recognize and validate students' funds of knowledge through course content, learning encounters are given relevance to students' lives, which, within a science context, has been shown to promote sustained interest in students from marginalized backgrounds (Basu & Calabrese Barton, 2007).

Although most educators understand the varied student experiences within their classrooms, it has been largely challenging for them to teach in a culturally congruent manner to students with varied backgrounds (Rodriguez, 2015). This incongruency has left diverse student populations feeling isolated within STEM classrooms (McGee, 2021). Equitable science curriculum models such as JCSP (Morales-Doyle, 2017) are being explored as ways to decrease the gap between students' lived experience and science content. Strategies like socioscientific modeling have implications for lessening the separation of students from science content by providing them a vehicle with which to model socioscientific phenomena from their particular cultural lens (Zeidler, 2014; Ke et al., 2021).

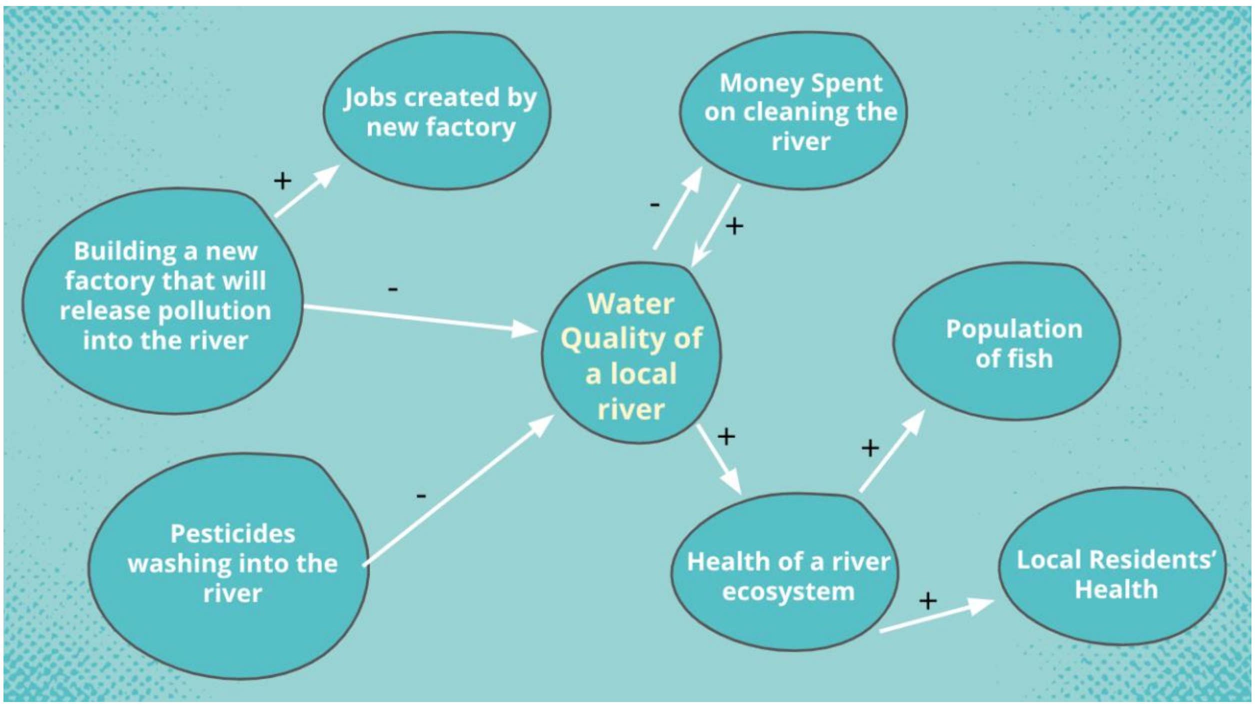
Socioscientific Modeling

Socioscientific models refer to representations that incorporate social factors alongside scientific factors for the purpose of better understanding, describing, predicting, or explaining socioscientific issues (Ke et al., 2021). Although these models can resemble models commonly encountered in science classes, they are inherently multidisciplinary in nature. Understanding, multi-faceted socioscientific issues necessarily involves weighing factors that fall outside the scope of what traditionally counts as "scientific" in nature (Zeidler, 2014).

Socioscientific models can take on many forms, however the model we focus on in this piece is a socioscientific system model which we refer to as a "system model" throughout the remainder of this piece. System models represent important system components within a labeled circle, as well as their relationships with other components using arrows. Although similar to concept maps, system models focus exclusively on cause and effect, whereas concept maps may include other relationships such as non-causal conceptual relationships like "fertilizer runoff is *a type of* pollution".

Figure 2 depicts a systems model representing the health of a river ecosystem. Whereas a strictly scientific model would focus on factors related to ecosystem dynamics such as predator/prey relations, a socioscientific model may expand upon this, incorporating ways that society shapes this ecosystem, the economic benefits of constructing a new factory and generating working-class jobs, and the risk that factory pollution may ultimately pose. Representing societal factors establishes groundwork for integrating modeling into discussions about social-justice issues, like the relationship between ecosystem health, environmental racism and social determinants of health. In holding space for knowledge derived from domains other than science like economics, politics, history, personal experiences, or community knowledge, socioscientific modeling presents an opportunity to generate a more holistic understanding of complex SJSI, a key aim of JCSP (Morales-Doyle, 2017).

Figure 2: Systems Model of Water Quality of Local River



With issues of equity stemming from widening wealth gaps, social determinants of health, and more, the COVID-19 pandemic has proven to be a prime example of an SJSI. The wide-ranging, systemic nature of these issues exacerbated by the emergence of the SARS-CoV-2 virus has made decision-making in the context of COVID-19 an exceptionally fraught matter. Decisions like whether to become vaccinated or wear a mask not only impact the decision-maker, but also shapes the physical, mental, and economic health of their community and society more broadly.

This was further complicated by the rapid generation of new knowledge to help manage uncertainty and inform policymakers and the public at large. We were challenged to integrate rapidly evolving knowledge from science, economics, politics, and other domains into our understanding of the world that we could make decisions that reflect the interests and values of ourselves and our fellow human beings. Socioscientific models are one resource to support people in doing so (Ke et al., 2021).

Context & Analysis

In spring of 2022, we recruited six participants to take part in an initial pilot study of how they use system models to understand viral pandemics. The participants were grouped into pairs to complete the exercise. The first session, Francesca and Faith (all names are pseudonyms), were undergraduate students at a predominantly white institution in the Southeast United States. Francesca and Faith both identify as women of color. Sam, Sadie, Tina, and Trinity were all seniors in their month of high school with plans to attend universities the following fall. Sam, Sadie, Tina, and Trinity identify as white: three as women and one as non-binary. Sam and Sadie were in the second session, and Tina and Trinity were in the third.

Participants were asked to engage in systems modeling activity while considering the driving question, "How has COVID-19 impacted your life?" At the time of the intervention, COVID-19 mandates were still largely in effect but were being lifted. Before asking the participants to build a COVID-19 systems model the researchers supported the participants in learning the conventions of a systems model using the issue of water quality in a local river. Once the participants demonstrated understanding of the water quality model, they were invited to create a systems model together that addressed the driving question.

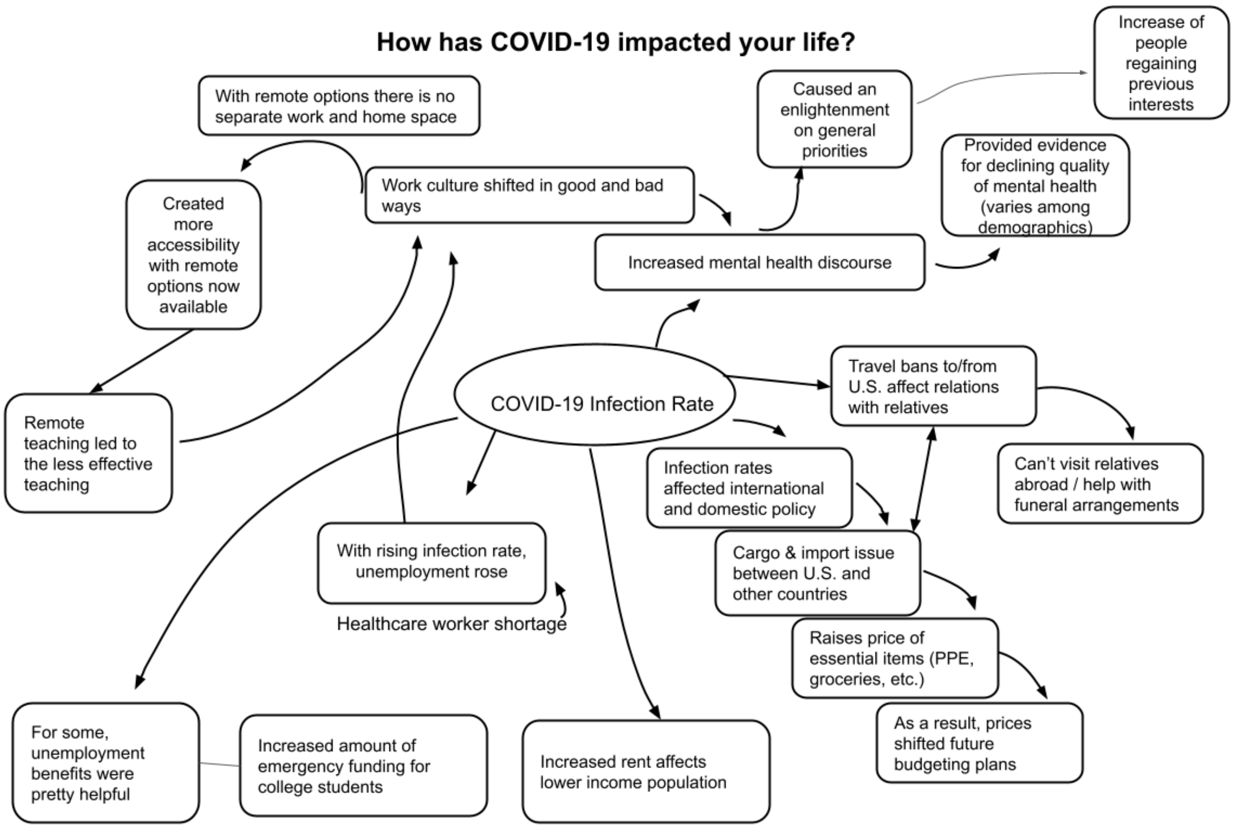
The participants were video and audio recorded as they created the systems model and audio recorded in an interview immediately following the experience. In total there was just over 180 minutes of recordings. Once the recordings were transcribed, the first three authors met weekly to review the transcripts, watch video, and discuss trends in data. The authors individually coded the transcripts looking for episodes where the participants made moves towards being a transformative intellectual: (a) reflected on their identity and position; (b) considered multiple perspectives; (c) included class, race, gender, or ability in their conversation; (d) wrestled with the complexity of the issue. For example, when participants questioned how to represent mental health, financial ramifications, and educational impacts all within one system, it was coded as an episode where the participants showed they were wrestling with the complexity of the issue. Each week the first three authors met to review codes as a group and final interpretations were made together. To ensure trustworthiness, track the development of ideas, and reflect on disagreements the authors kept personal analytic memos as well as running documentation of group meetings.

Findings

Participants produced a detailed systems model that shows the complexity of the COVID-19 pandemic. By making visible the connections among elements of an issue, the system model encourages analysis of how elements affect one another in direct and indirect ways, allowing it to be a product tool for sensemaking. Figure 3 shows the sophisticated understanding Francesca and Faith came to represent using the system model. Figure 3 is a digital copy of the session one's system map. It was recreated digitally for size and legibility.

To address our research question, we present an overview of three major findings that emerged from our pilot study. We see evidence of students demonstrating profound insight into SJSI, constructing understandings of the issue that meaningfully align with their experiences and goals, and engaging in sophisticated reasoning skills. We next focus on how these findings support systems modeling as a strategy for implementing justice-centered science pedagogy.

Figure 3: Session 1 systems model



Students demonstrating profound insight into SJSI

Figure 3 demonstrates how Francesca and Faith engaged with the SJSI. The two worked together to demonstrate the complex ways COVID-19 impacted their lives personally and the broader society. Working through building their systems model, Francesca and Faith navigated the multifaceted, interconnected nature of the SJSI to make visible the ways scientific factors and social impacts intersect. The excerpt below is from Francesca and Faith's session.

Francesca	I feel like this [education, unemployment rates, and working from home are] connected. I feel like it's all connected...
Faith	They are all connected.
Francesca	To mental health. I was going to say, this education issue, this issue with financial, it both ends up connecting to mental health.

The conversation between Francesca and Faith shows how they were coming to appreciate the complexity of the issue. By identifying the non-linear relationships between infection rates and education, finances, and mental health they are making sense of complex systems and the potential impacts these systems have on society.

In her interview, Francesca said,

> Putting it all like this [in a systems map], it should help me. Like, first I started off like education and then we went into like financial. And then whenever Faith was going over, um, mental health, that's where - if I hadn't seen it all put together like this, I wouldn't have been able to like make the connections where these two things are connected to mental health, and now it's visually here so, I can see that. Um, but that kind of - it helped me make better connections.

Francesca highlights how pulling from her own and Faith's funds of knowledge helped her construct a more sophisticated understanding of the issue. Faith and Francesca made significant steps in recognizing that SJSI are not isolated incidents but are often connected to broader systems. As students create these models, they are challenged to deconstruct the systems that govern complex phenomena like SJSI into their basic components, aiding in their ability to identify causal mechanisms that drive system level behaviors (Bechtel & Abrahamsen, 2005).

Constructing understandings that are personally meaningful

Systems modeling considers how participants make sense of the phenomena, how they embed that meaning within their experiences, and what knowledge and skills the students use to support these processes. In this way, students can pull from their personal funds of knowledge to negotiate complex issues. We found evidence of this across all three sessions.

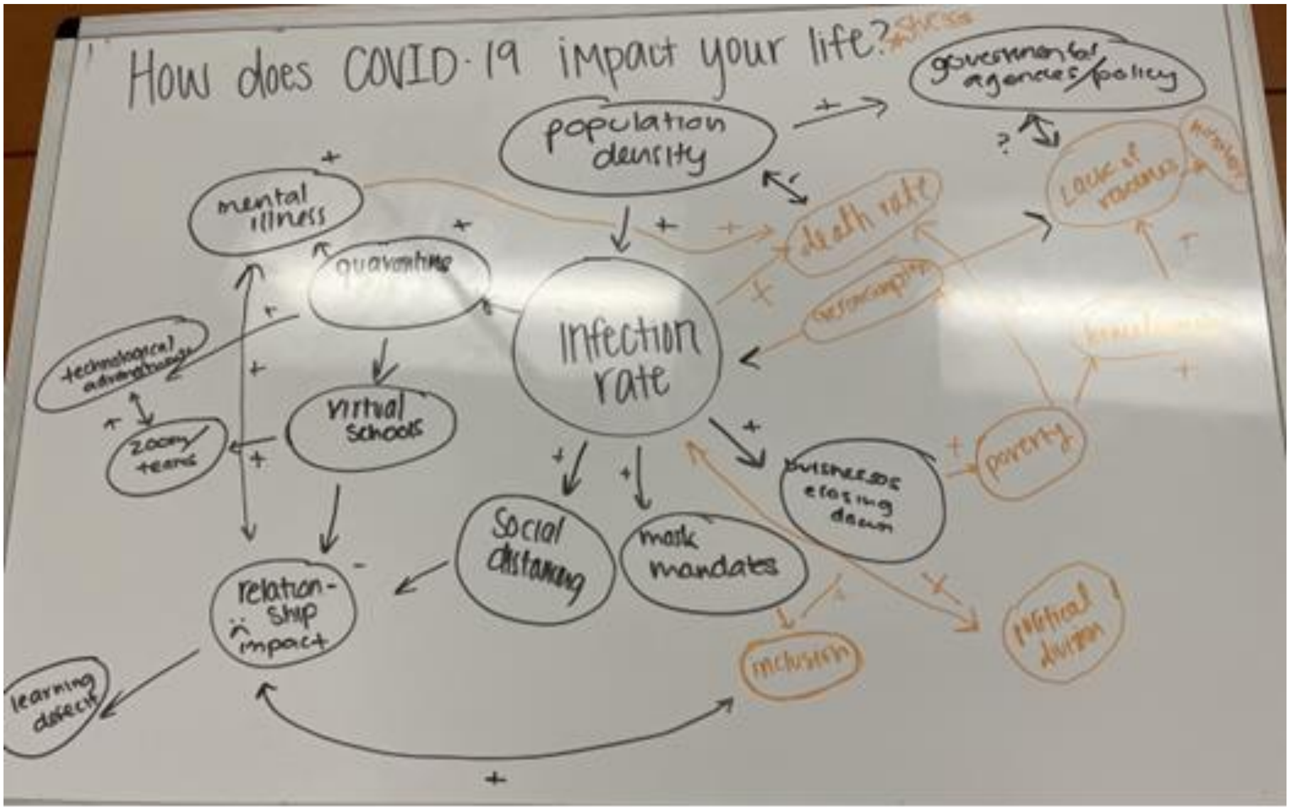
Sadie reflected on the ways she tied the modeling exercise to her personal experience.

> I mean, honestly, it just kind of goes into like all the details of COVID that like for - well, Sam and I, when we were thinking of all the ideas, I feel like we kind of we're pulling through like our own experiences, so that kind of explains like personally how it impacted my life. We kind of just like pulled a bunch of different details, so it kind of shows like - or I want to think that it shows the like whole picture of like what happened during COVID, um, and like not just like one aspect of it. I feel like it's kind of holistic.

For Sadie, the model did not simply represent the ways the virus spreads, but also, the ways the pandemic impacted Sadie and Sam's lives. For example, when making their systems model, Sadie and Sam both pulled from their personal experiences with switching to virtual platforms as demonstrated in Figure 4. They each showed exasperation with virtual learning and the impact on relationship but at the same time appreciated that technology was still providing a platform for maintaining friendships.

Sadie	So, start with virtual schools and then like technological advancements
Sam:	Yeah, but we need something broader.
Sadie:	Yeah, because then everything was online. Like my mom used meet up with her friends over Zoom.

Figure 4: Session 2 systems model



Trinity also used her personal experiences when constructing their model

> "I think it's [the model is] a personal thing that a lot of people could experience and yeah, I just recently had COVID, so the isolation was definitely a lot and kind of related to like the death like, like I have old family members and like that affected me personally. And the labor shortage, my dad owns a business so he's like been having trouble getting like consistent employees so that definitely affected my family."

By drawing from her accumulated, firsthand knowledge, Trinity tied her understanding of COVID-19 into complex societal problems such as labor shortages.

Honoring the social dimensions ordinarily omitted from scientific modeling helped students to meaningfully engage in the exercise and participate in ways they normally would not have. For instance, Francesca mentioned in her interview that this type of model is "just easier to read than having a bunch of scientific language that's just thrown at me." By increasing the accessibility of the model, it becomes a more equitable practice. Participants linked disciplinary knowledge with other social dimensions and made visible the ways that scientific factors, such as infection rates, and students' personal experiences, such as housing shortages, are connected in ways that would not have been possible otherwise. In this way, content knowledge can be viewed as a tool for making sense of inequitable systems and societal injustices.

Engaging in sophisticated reasoning skills

Socioscientific reasoning is a construct intended to capture some of the thinking skills necessary for the thoughtful negotiation of complex issues. While certainly not inconsistent with scientific norms, socioscientific reasoning skills highlight patterns of thinking that are not captured explicitly by the science and engineering practices featured in the NGSS. Socio-scientific reasoning skills include considering issues from multiple perspectives and identifying what additional knowledge is needed to address an issue (Sadler et al., 2007). We found evidence of students developing their socio-scientific reasoning skills as they wrestled with ways to represent their diverse experiences with the SJSI. Below is an excerpt from Trinity's interview.

Interviewer	Yeah. Um, did you notice or can you remember any instances where you and your partner had a different experience that you were trying to represent on the model?
Trinity	Um, I guess, um, like with labor shortage, um, [Tina] was kind of thinking of like quarantining and having, like, employees being sick. And I was kind of thinking of it more like, um, like a lot of places are hiring because they just don't have enough employees in general. So, I think there might have been like not disagreement, but we were just kind of thinking like from two different stances on that.
Interviewer	So, how did you all decide to represent it this way?
Trinity	I think we kind of more just looked at it from a, like, bigger lens, as opposed to like - like we kind of put labor shortage as

> just both of those things, instead of like narrowing it down to one.

The interview shows how Trinity and Tina had to navigate their diverse experiences and to move beyond a single perspective. The shows the ways the exercise pushed them to understand the issue more fully from multiple perspectives to make visible the ways social forces and scientific factors play out in society.

We also observed several instances where learners identified gaps in their current knowledge. For instance, Faith commented on supply chain shortages for protective personal equipment. She pointed out that she did not know why the shortages were happening, but that they were affecting society in various ways such as healthcare workers and people trying to protect themselves as businesses started to reopen. Through this exercise she identified a weakness in her own knowledge and how this societal factor has meaningful consequences. Students who develop socioscientific reasoning skills are able to analyze and evaluate complex issues, identify root causes, anticipate potential consequences, and develop informed and effective strategies for addressing these issues, a key factor in transformative science education.

Systems Modeling as a Justice-Oriented Science Practice

From our findings, we contend that system models are well-aligned to justice-centered science pedagogy for several reasons. First, these models are particularly well equipped to provide students with a more robust understanding of complex SJSI than traditional scientific modeling practices. Second, socioscientific system models present an opportunity for students to construct understandings of issues that are meaningfully aligned with their experiences and goals. Finally, we contend that developing sophisticated reasoning skills in the face of complex issues is conducive to supporting learning even if that learning is not captured on standardized assessments.

Robust Understanding of the complexity of SJSI

These models are particularly useful in negotiating SJSI because of how they integrate information and evidence from different disciplines (e.g., civics, sociology, economics) into a single model. By drawing connections between scientific knowledge and other social dimensions these models capture a more nuanced understanding of how science and society intersect. Whereas typical approaches to modeling are limited to explaining scientific phenomena because they draw only from scientific evidence, socioscientific models are better suited to navigating SJSI because they embrace a wider array of wider array of evidence, and these different forms of evidence have different standards for assessing the quality of that evidence. In holding space for knowledge from other domains socioscientific modeling presents the opportunity to generate a more holistic, useful understanding of complex SJSI, a key aim of justice-centered science pedagogy (Morales-Doyle, 2017).

Both the material and societal systems implicated in SJSI are notoriously complex, as seen with the COVID-19 pandemic. There is an abundance of research demonstrating that students struggle to think about complex systems (Hmelo-Silver et al., 2007; Wilensky & Jacobson, 2014; Yoon, 2018), and identify complex causal relationships (Grotzer, 2012; Grotzer & Tutwiler, 2014). To make matters worse, people often default to essentialist explanations for systemic inequality because the societal structures that drive systemic inequalities are difficult to observe and therefore less salient (Amemiya et al., 2022). Understanding these dynamics when considering SJSI are crucial, as they can be immensely consequential when trying to explain, predict the behavior of, or intervene to address complex SJSI. Constructing models that explicitly identify causal relationships can better position students to consider complex relationships that are often overlooked in favor of more simple, but less accurate explanations (Hanisch & Eirdosh, 2021).

Constructing understandings that are personally meaningful

Systems models present an opportunity for students to construct understandings of issues that are meaningfully aligned with their experiences and goals. Although the literature on the affordances and approaches to engaging in modeling is extensive (Louca & Zacharia, 2012), there have recently been concerns raised about the narrow conceptions of what counts as modeling, how modeling is assessed, and how modeling research is framed. Schwarz and colleagues (2022) argue that modeling as curriculum and modeling as research are often done in ways that do not consider the utility of the practice to the students. For example, positioning the creation of a model as the end goal of an activity may provide a window into how students conceptualize an issue, but this strips modeling of the epistemic power that allows students to construct new understandings of phenomena (Schwarz et al., 2022). In these instances, modeling is more meaningful to evaluators than the students we ultimately hope to support.

Although difficult to capture, the entanglement of modeling practice with the histories, goals, and social contexts of learners must be considered when deciding what modeling should look like, and how it should be assessed (Berland et al., 2016). For instance, Kirk et al. (in review) found that students were more interested in pragmatic actions, societal impacts, and less interested in technical aspects emphasized in science instruction related to SSI. Instead of asking students to construct abstract models of science content, students can construct models that relate abstract science content to their daily lives. With systems modeling as a strategy, students are given a tool to construct such model. As seen across all three sessions, but most clearly in session two, Sadie and Sam pulled from their personal experiences to engage in sensemaking in a way that meaningfully aligns to them, and we suspect, their goals for science education.

By broadening the scope of what can be considered a “valid” intellectual contribution to a model, students are presented with more ways to draw upon their experiences, expertise, and interests to construct a model that meaningfully aligns with their goals and how they see themselves in relation to science content. Doing so provides students with a chance to construct a resource steeped in personal meaning that illustrates ways they can use their knowledge to inform their actions and achieve their goals.

Conducive to academic learning

Finally, we contend that incorporating societal factors into SSI-related modeling experiences is conducive to supporting students’ academic learning. It is important for students to master and critique scientific knowledge to fully participate in educational institutions and society as it currently exists (Morales-Doyle, 2017). Students having success with content and skills that are typical gatekeepers to success in science courses and fields is necessary for youth to leverage their science education as a means to engage in transformative action (Bang and Vossoughi, 2016). Therefore, academic achievement does not need to be positioned as at odds with or in competition with students’ commitments to social change. Transcending this tension can look like academic achievement being interwoven with development of critical consciousness which is an understanding of academic learning that cannot be captured on a standardized test (Laughter & Adams, 2012). To build critical consciousness, students need to recognize the complexities and interdependencies of social and scientific issues through engaging in constructive dialogue with diverse perspectives. One such way to do this is for learners to apply and build competencies for socioscientific reasoning; a skill that helps make science usable as a tool for informed decision making. We saw evidence across all three sessions that systems modeling supported students in engaging in socioscientific reasoning through considering multiple perspectives and identifying gaps in their current knowledge. In this way, systems modeling is emerging as a strategy for developing sophisticated reasoning skills, which in turn can support academic success.

Ladson-Billings (1995) positioned academic competence withing culturally relevant pedagogy because it is important that students develop their academic skills to be successful in the classroom and beyond. She suggested that the "trick" of academic competency is to get students to choose academic excellence. JCSP leverages interesting, relevant SJSI as a persuasive tool in getting learners to find value in their academic success. By creating modeling opportunities that capture aspects of an issue that students are more likely to be interested in, socioscientific systems modeling has the potential to develop students' interest. Interest has been shown to support outcomes relevant to making sense of complex socioscientific issues like persistence in the face of difficult reading tasks, being able to integrate information from multiple sources and perspectives and evaluate information to make informed decisions (Bråten and Braasch, 2017; Soemer & Schiefele, 2019; Strømsø et al., 2010). Additionally, Ladson-Billings (1995) calls for appealing to students culturally rooted interests as a motivator to students choosing academic excellence.

Likewise, the practice of constructing and using these models remains aligned with *Framework* (2012) and NGSS (NGSS Lead States, 2013) despite their interdisciplinarity. In constructing socioscientific system models, students can develop competence in the practice of *developing and using models,* as well as consider two crosscutting concepts: *systems and system models,* and *cause and effect.* Developing modeling competence has become one of the major goals in science education and has been found to be a powerful tool for supporting students in science learning (Louca & Zacharia, 2012). In remaining aligned with the NGSS, socioscientific modeling works to ensure that students can experience academic achievement as defined by prominent policy documents, a key criterion for justice-centered science pedagogy (Morales-Doyle, 2017).

Future Directions

Although we acknowledge the small scale of our study as a limitation, we believe our data show promise for socioscientific modeling as a concrete tool for teachers implementing a justice-centered science pedagogy. As we contemplate future instructional reforms, it is imperative that we actively work towards designing opportunities for students to engage in education in affirming and meaningful ways. We share in the concern that Shwarz et al. (2022) outlined that our field's work on modeling "is largely based on the European Western scientific canon that values abstracted representational knowledge" (p. 4). This narrow approach limits opportunities for students to engage in the practice in a manner that acknowledges their contributions to knowledge and culture. By breaking from this tradition, educators can support students in ways that encourage them to take transformative action in ways that are personally meaningful.

Socioscientific system models explicitly identify causal relationships and can better position students to consider complex relationships that are endemic to SJSI. Broadening the scope of what can be considered a "valid" intellectual contribution to a model, expands the ways students can engage in modeling that aligns with their goals and how they see themselves in relation to science content. Creating modeling opportunities that capture aspects of an issue that students are more likely to be interested in, has the potential to appeal to students' interest, which has been shown to support outcomes relevant to academic achievement (Linnenbrink-Garcia et al., 2016; McGee & Bentley, 2017). By incorporating forms of knowledge and ways of knowing often overlooked in traditional modeling experiences, our participants demonstrated a modeling practice rich with personal knowledge and meaning. Through these affordances, socsioscientific modeling is well positioned to create a higher quality, more equitable modeling experience.

It is important to note that socioscientific modeling is only one component of reform-oriented teaching. Educators need to accompany this approach with other intentional scaffolds such as engaging in discourse around equity-based content and uncovering power dynamics (Brown B.A., et al., 2019; Laughter & Adams, 2012). With this work, we hope to expand how the science education community views modeling and for what purpose. Socioscientific modeling creates opportunities for students to engage with a phenomenon in ways that are not normally available in more traditional scientific modeling experiences making it conducive to the goals Morales-Doyle put forth with JCSP.

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