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Socioscientific modelling as an approach towards justice-centred science pedagogy

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Abstract

Justice-centred science pedagogy has been suggested as an effective framework for supporting teachers in bringing in culturally relevant pedagogy to their science classrooms; however, limited instructional tools exist that introduce social dimensions of science in ways teachers feel confident navigating. In this article, we add to the justice-centred science pedagogy framework by offering tools to make sense of science and social factors and introduce socioscientific modelling as an instructional strategy for attending to social dimensions of science in ways that align with justice-centred science pedagogy. Socioscientific modelling offers an inclusive, culturally responsive approach to education in science, technology, engineering, the arts and mathematics through welcoming students' diverse repertoires of personal and community knowledge and linking disciplinary knowledge with social dimensions. In this way, students can come to view content knowledge as a tool for making sense of inequitable systems and societal injustices. Using data from an exploratory study conducted in summer 2022, we present emerging evidence of how this type of modelling has shown students to demonstrate profound insight into social justice science issues, construct understandings that are personally meaningful and engage in sophisticated reasoning. We conclude with future considerations for the field.

Keywords justice-centred science; culturally relevant science teaching; socioscientific issues; system modelling

Introduction

A Framework for K–12 Science Education (NRC, 2012) is codified in the Next Generation Science Standards (NGSS Lead States, 2013) in the United States. The NGSS 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 (NGSS Lead States, 2013). Similar commitments have been made elsewhere, including the National Curriculum for Science in England, emphasising students communicating scientific ideas effectively (Ryder and Banner, 2011), and The Australian Curriculum, which provides a framework for developing students' skills (Treagust et al., 2015). These commitments prioritise students figuring out and developing conceptual understanding of natural phenomena through engaging in epistemic practices such as modelling (Berland et al., 2016; Duschl, 2008). The research on which these reforms are based emphasises students participating in knowledge-building processes through disciplinary work. In many instances, however, science learning environments do not make these types of knowledge-building opportunities available to students from historically minoritised communities, because traditional pedagogical orientations and instructional approaches fail to appreciate the diverse repertoires of cultural practices, knowledge, experiences and motivations that students bring with them to the classroom (Bang et al., 2012; Rosebery et al., 1992).

The implementation of standards depends on school systems and educators tailoring curricula and instruction to meet these reform-oriented approaches for their local contexts. Garibay (2015) found that historically minoritised students report caring more about science when it is used 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, 2006; Lipman, 2004). Education in science, technology, engineering, the arts and mathematics (STEAM) offers a sociocultural model of science education that integrates traditional conceptions of science learning with the arts (Kahn and Zeidler, 2016; Zeidler, 2016). In doing so, STEAM education is a model for contextualising science learning in contexts to the same degree as sociology, history and fine arts to make such learning personally meaningful. One method of contextualising learning in this way is through issues-based teaching, where the issues are embedded in broader sociocultural contexts that require interdisciplinary approaches, such as STEAM, to sufficiently engage with the issues.

Morales-Doyle (2017) proposes justice-centred science pedagogy (JCSP) as a framework for science instruction. Drawing on Ladson-Billings's (1995) culturally relevant pedagogy, JCSP calls for students to be held to high academic achievement standards and to be positioned as producers of knowledge and culture while grappling with issues with direct social justice implications. A challenge of this pedagogical approach is that even teachers who embrace critical pedagogies struggle to incorporate social and personal dimensions of science into their instruction (Bossér et al., 2015; Ekborg et al., 2013; Friedrichsen et al., 2021; Lazarowitz and Bloch, 2005). 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 recognise a discontinuity between theory and practice. Therefore, we ask how does system modelling, which involves a specific type of socioscientific model, support justice-centred science learning?

We introduce socioscientific modelling as a strategy that privileges equity and access to science practices, which is aligned with the *Framework for K–12 Science Education* (NRC, 2012), while building on the pedagogical foundations laid out by JCSP. Socioscientific modelling creates opportunities for students to contextualise science content in relation to their experiences and to issues that are important to them. By engaging in this form of modelling, students unpack complex causal relationships while considering the full impact of the underlying socioscientific issues. Following a review of relevant literature, we present emerging evidence from student engagement in socioscientific modelling for JCSP. We end this article with recommendations for the field.

Theoretical framing

Justice-centred science pedagogy

In response to calls for K–12 science learning to be a space for challenging inequality, Morales-Doyle (2017) advanced JCSP as a framework that prioritises social transformation in science instruction. Using principles of culturally relevant pedagogy (Ladson-Billings, 1995) and social transformation (Freire, 2018), 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). Scrutinising 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 minority students (Aikenhead, 2006; Akom et al., 2013; McGee and Bentley, 2017). This critical justice stance for science pedagogies is scarce in current literature (Calabrese Barton et al., 2020). Therefore, to fully appreciate and add to the limited research theorising social justice in science education, one must understand culturally relevant pedagogy and how JCSP aligns with the framework that Ladson-Billings (1995) offered decades ago (B.A. Brown et al., 2019; Calabrese Barton et al., 2020; Rodriguez, 2015).

Critical pedagogies

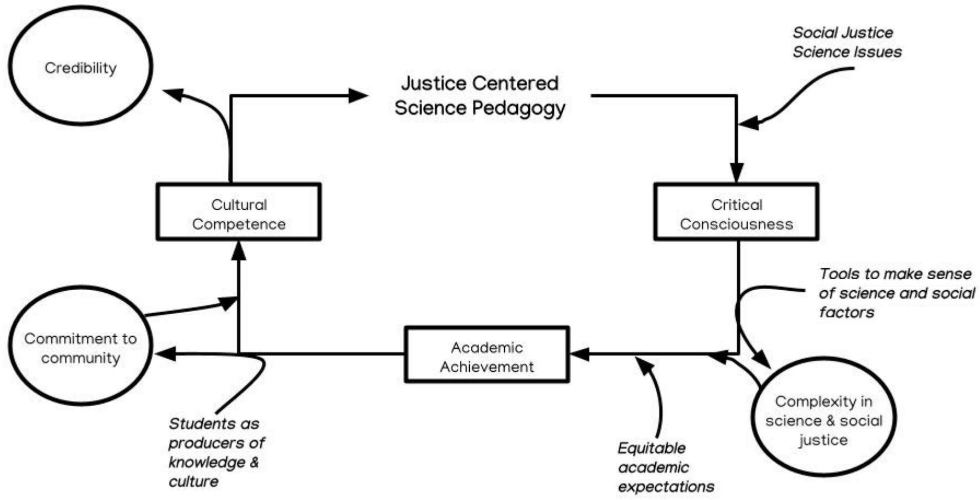
Culturally relevant pedagogy is a way of teaching that uses academic content and the learning process to empower students to challenge social inequity (Ladson-Billings, 2000; Mensah, 2011). Culturally relevant pedagogy goes beyond disciplinary facts and concepts to empower students to critique and apply knowledge and deconstruct social inequality through three principles: academic success; cultural competence; and 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, 2006, 2009). 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 of particular importance to students' communities or lives (Underwood and Mensah, 2018). Last, 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, to investigate the many factors that have contributed to the problem and to 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, 2012; Freire and Macedo, 1987). Teachers who 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; Gayford, 2002; Lee et al., 2006). For culturally relevant pedagogy to be fully operationalised, all three principles must be acknowledged and implemented in the classroom, which entails considering how to support teachers in bringing criticality to their classrooms.

Justice-centred science pedagogy 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 illustrates JCSP as a catalyst for social change.

Figure 1. Justice-centred science pedagogy with socioscientific modelling (Source: adapted from Morales-Doyle, 2017: 1055)



As Figure 1 shows, JCSP builds on the tenets of culturally relevant pedagogy (in rectangles) and calls attention to what students get out of JCSP-based instruction (in circles). When treated as 'transformative intellectuals', students exhibit 'complex thinking about SJSI [social justice science issues], [cultivate] commitment to their cultures and communities, and [earn] credibility as members of a marginalised community who are developing scientific expertise while they also develop an appreciation for its limits as one way of knowing' (Morales-Doyle, 2017: 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 (B.A. Brown et al., 2019; Dimick, 2012).

Morales-Doyle (2017) also offers three pedagogical components (in italics), and we offer an additional fourth one. The first component – *using a social justice science issue as a curricular focus* – prompts students to examine complex, often controversial, issues with both science and social components. These types of issues are commonly called socioscientific issues. Morales-Doyle (2017) goes beyond previous frameworks for socioscientific issues by emphasising 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 similar frameworks (Zeidler et al., 2005), in that the problems posed are rooted in social inequality and cannot be understood without addressing oppression. Morales-Doyle (2017) calls these particular socioscientific issue problems *social justice science issues* (SJSIs). By bringing the outside world into the classroom, JCSP erodes barriers that inhibit engagement with relevant contexts and fosters a more interdisciplinary, STEAM approach (Davis and Schaeffer, 2019: 369; Trinidad, 2011). The next component Morales-Doyle offers is *maintaining equitable academic expectations*, in other words, holding teachers accountable to the belief that students can understand and develop robust understandings of SJSIs (B.A. Brown et al., 2019; J.C. Brown, 2017). This understanding should not be limited by standardised tests, but rather explored in students' willingness to wrestle with complex issues and apply science content in usable ways (Laughter and Adams, 2012). Last, 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. To these three pedagogical components, we add *tools to make sense of science and social factors*, because students need meaningful tools to engage in sophisticated sensemaking. We will explore this component later in this article.

In advancing a pedagogical model that leverages principles of Ladson-Billings's (1995) culturally relevant teaching and Freire's (2018) social transformation, privileged forms of science are problematised 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 well-being (Moll and Greenberg, 1990). Initial analysis of the concept (Moll et al., 1992) was undertaken to support K–12 educators in adapting classroom teaching and curriculum to students' unique contexts (Denton and Borrego, 2021). Utilisation of students' funds of knowledge is a specific aspect of culturally relevant teaching practices that affirm students' identities by positioning them as experts within their own experiences, and, in doing so, view their unique cultural experiences through an asset-based lens (Ladson-Billings, 2009; Smith et al., 2022).

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 recognise and validate students' funds of knowledge through course content, learning encounters become relevant to students' lives, which, within a science context, has been shown to promote sustained interest among students from marginalised backgrounds (Basu and Calabrese Barton, 2007).

Although most educators understand the varied student experiences within their classrooms, it has been challenging for many of 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 science, technology, engineering and mathematics (STEM) classrooms (McGee, 2021). Equitable science curriculum models such as JCSP (Morales-Doyle, 2017) are being explored to decrease the gap between students' lived experience and science content. Strategies such as socioscientific modelling have implications for lessening the separation of students from science content by providing them a vehicle to model socioscientific phenomena through their own cultural lens (Ke et al., 2021; Zeidler, 2014).

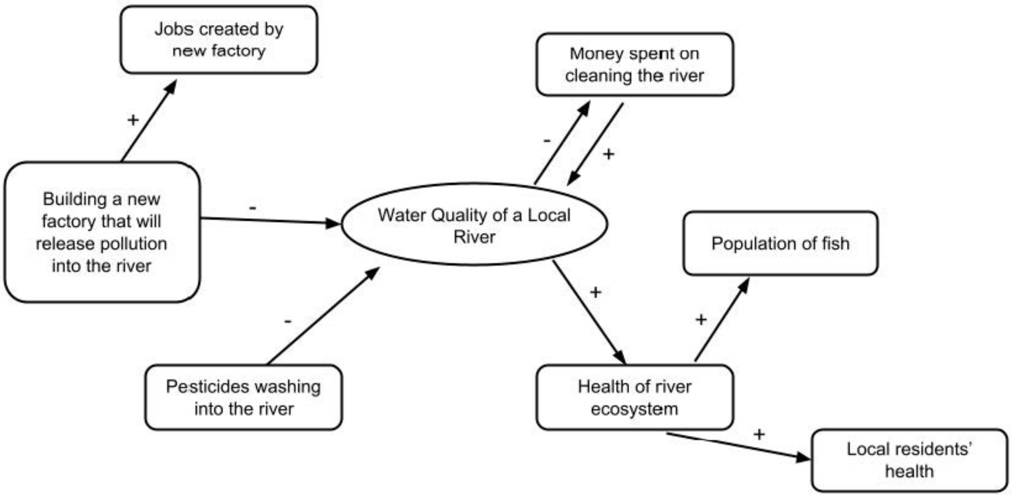
Socioscientific modelling

Socioscientific models refer to representations that incorporate social factors alongside scientific factors to better understand, describe, predict or explain socioscientific issues (Ke et al., 2021). Although these models can resemble models commonly encountered in science classes, they are interdisciplinary in nature because they integrate knowledge across disciplines into one coherent representation. Understanding multifaceted socioscientific issues involves weighing factors that fall outside the scope of what traditionally counts as scientific (Zeidler, 2014).

Socioscientific models can take on different forms; the model we focus on in this article is a socioscientific system model which we refer to as a *system model* throughout the remainder of the article. System models represent important system components within labelled circles, as well as their relationships with other components using arrows. Figure 2 depicts a system model representing the health of a river ecosystem. Although similar to concept maps, system models focus exclusively on cause-and-effect connections between factors. For example, in Figure 2, pesticide run-off causes impacts on water quality. In contrast, concept maps may include other kinds of relationships, such as non-causal conceptual relationships – for example, fertiliser run-off is *a type of* pollution.

Whereas a strictly scientific model would focus on factors related to ecosystem dynamics, such as the predator–prey relationship, a socioscientific model may expand on this, incorporating ways that society shapes the ecosystem, the economic benefits of constructing a new factory and the risks that factory pollution may generate. Representing societal factors establishes groundwork for integrating modelling into discussions about social justice issues, such as the relationship between ecosystem health, environmental racism and social determinants of health. In holding space for knowledge derived from domains other than science, such as economics, politics, history, personal experiences and community knowledge, socioscientific system modelling presents an opportunity to generate a more holistic understanding of complex SJSIs, a key aim of JCSP (Morales-Doyle, 2017).

Figure 2. System model of water quality of a local river



Covid-19 as a social justice science issue and a topic for socioscientific modelling

With issues of equity stemming from widening wealth gaps and social determinants of health, 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 such as whether to be vaccinated or wear a mask not only impacted the decision maker, but also shaped the physical, mental and economic health of their community and society more broadly.

The rapid generation of new knowledge added further complication. We were challenged to integrate rapidly evolving knowledge from science, economics, politics and other domains into our understanding of the world, so that we could make decisions that reflect the interests and values of ourselves and our fellow human beings. When integrated into STEAM education, delving into the pandemic provides a relevant and compelling context for interdisciplinary learning and exploration, making it a promising avenue for fostering skills and knowledge needed to address future challenges with a social justice lens. Socioscientific system models are one resource to support people in doing this kind of work (Ke et al., 2021).

Context and analysis

In spring 2022, we recruited six participants to take part in a study to explore how students use socioscientific models to understand viral pandemics. This study was part of a larger design research programme focused on supporting multi-language learners' understanding of socioscientific issues through modelling. The initial purpose was to test an early iteration of our curriculum; however, as learners participated, we noticed that the ways in which learners engaged in the tasks aligned with JCSP, which provided us with an interesting opportunity to explore the relationship between socioscientific issues-based teaching and justice-centred pedagogies.

The participants worked in pairs to complete the exercise. Francesca and Faith (all names are pseudonyms), two undergraduate students at a predominantly White institution in the south-east United States, participated in the first session. Francesca and Faith both identify as women of colour. Sam, Sadie, Taylor and Trinity were all in their last month of high school, with plans to attend universities the following autumn. Sam, Sadie, Taylor and Trinity identify as White; Sam, Sadie and Trinity identify as female, and Taylor as non-binary. Sam and Sadie were in the second session, and Taylor and Trinity were in the third.

Participants were asked to engage in system modelling 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 system model,

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researchers provided instruction about the conventions of system modelling 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 system model that addressed the driving question.

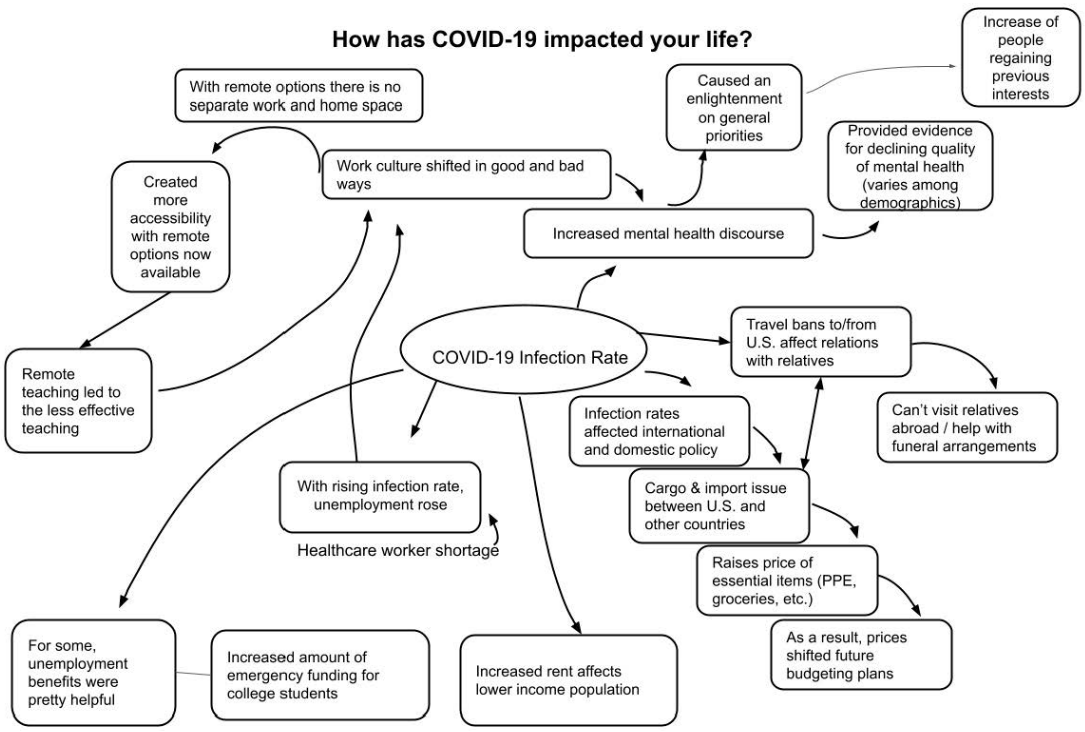
Participants were video and audio recorded as they created system models (in pairs), and audio recorded in an interview (as individuals) immediately following the experience. In total, there were over 180 minutes of recordings. Once the recordings were transcribed, the first three authors met weekly to review the transcripts, watch videos and discuss trends in the data. The authors individually coded the transcripts looking for episodes where participants made moves towards being a transformative intellectual: (1) reflected on their identity and position; (2) considered multiple perspectives; (3) included class, race, gender or ability in their conversation; and (4) wrestled with the complexity of the issue. For example, when participants questioned how to represent mental health, financial ramifications and educational impacts within one system, it was coded as an episode where participants showed that they were wrestling with issue complexity. After several iterations of individual coding, group review and revision of codes, the authors collectively generated the final interpretations reported here. To ensure trustworthiness, to track the development of ideas and to reflect on disagreements, the authors kept personal analytic memos and running documentation of group meetings.

Findings

Participants produced detailed system models that show the complexity of the Covid-19 pandemic. By making visible the connections among elements of an issue, the system models encourage analysis of how elements affect one another directly and indirectly, allowing it to be a productive tool for sensemaking. Figure 3 shows the sophisticated understanding that Francesca and Faith came to represent in their system model – a digital copy of the model they created on a whiteboard.

In the sections that follow, we present an overview of three major findings that emerged from analysis of the modelling sessions and interviews. We see evidence of students demonstrating profound insight into SJSIs, 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 system modelling as a strategy for implementing JCSP.

Figure 3. Session 1 system model



Students demonstrating profound insight into social justice science issues

Francesca and Faith worked together to demonstrate the complex ways in which Covid-19 impacted their lives and broader society. In building their system model, Francesca and Faith navigated the multifaceted, interconnected nature of the SJSI to make visible the ways in which scientific factors and social impacts intersect. This excerpt from Francesca and Faith's session demonstrates this trend:

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 interconnectedness of the issue. By identifying the non-linear relationships between infection rates and education, finances and mental health, they were making sense of complex systems and their potential impacts on society. In her interview, Francesca said:

> Putting it all like this [in a system model], it should help me. First, I started off [with] education and then we went into financial. And then whenever Faith was going over mental health, that's where – if I hadn't seen it all put together like this, I wouldn't have been able to make the connections where these two things are connected to mental health, and now it's visually here so, I can see that. But 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 recognising that SJSIs 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 such as SJSIs into their basic components, aiding their ability to identify causal mechanisms that drive system-level behaviours (Bechtel and Abrahamsen, 2005).

Constructing understandings that are personally meaningful

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

Sadie reflected on the ways she tied the modelling exercise to her personal experience:

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

For Sadie, the model did not simply represent how the virus spreads, but also the ways in which the pandemic impacted Sadie's and Sam's lives. For example, when making their system model, Sadie and Sam both pulled from their personal experiences of switching to virtual platforms. They each showed exasperation with virtual learning and its impact on relationships, but, at the same time, appreciated that technology provided 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.

Trinity also used her personal experiences when constructing her model:

> I think it's [the model] 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 the death rate, like I have old family members, and that affected me personally. And the labour shortage, my dad owns a business, so he's been having trouble getting consistent employees, so that definitely affected my family.

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

Honouring the social dimensions ordinarily omitted from scientific modelling 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, essential for JCSP.

Engaging in sophisticated reasoning skills

Socioscientific reasoning is a construct intended to capture some of the thinking skills necessary to thoughtfully negotiate complex issues. While certainly not inconsistent with scientific norms, socioscientific reasoning highlights patterns of thinking not captured explicitly by the science and engineering practices featured in the NGSS (NGSS Lead States, 2013). Socioscientific reasoning skills include considering issues from multiple perspectives and identifying additional knowledge needed to address an issue (Sadler et al., 2007). We found evidence of students developing their socioscientific reasoning skills as they wrestled with ways to represent their diverse experiences with the SJSI. This is an excerpt from Trinity's interview:

Interviewer	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	I guess, with labour shortage, [Taylor] was kind of thinking of quarantining and having employees being sick. And I was kind of thinking of it more like a lot of places are hiring because they just don't have enough employees in general. So, I think there might have been not disagreement, but we were just kind of thinking from two different stances on that.
Interviewer	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, we kind of put labour shortage as just both of those things, instead of like narrowing it down to one.

The interview shows how Trinity and Taylor had to navigate their diverse experiences and move beyond a single perspective. This shows how 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 the participants identified gaps in their current knowledge. For instance, Faith commented on supply chain shortages for personal protective 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 for healthcare workers and people trying to protect themselves as businesses started to reopen. Through this exercise, she identified a weakness in her knowledge, and how this societal factor has meaningful consequences.

Students who develop socioscientific reasoning skills are able to analyse 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.

System modelling as a justice-oriented science practice

From our findings, we contend that socioscientific system models align well with JCSP for several reasons. First, these models are particularly well equipped to provide students with more robust understandings of complex SJSIs than traditional scientific modelling 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 standardised assessments.

Robust understanding of the complexity of social justice science issues

Socioscientific system models are useful tools for negotiating SJSIs because they integrate information and evidence from different disciplines (for example, civics, sociology and 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 modelling are limited to explaining scientific phenomena because they draw only from scientific evidence, socioscientific models are better suited for navigating SJSIs because they embrace a wider array of evidence. These different forms of evidence have different standards for assessing the quality of that evidence. In holding space for knowledge from other domains, socioscientific modelling presents opportunities to generate more holistic, useful understandings of complex SJSIs, a key aim of JCSP (Morales-Doyle, 2017).

The material and societal systems implicated in SJSIs 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 and Jacobson, 2014; Yoon, 2018) and to identify complex causal relationships (Grotzer, 2012; Grotzer and 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, are less salient (Amemiya et al., 2022). Understanding these dynamics when considering SJSIs is crucial, as they can be immensely consequential when explaining, predicting the behaviour of or intervening to address complex SJSIs. Constructing models that explicitly identify causal relationships can better position students to consider complex relationships that are often overlooked in favour of simpler but less accurate explanations (Hanisch and Eirdosh, 2021).

Constructing understandings that are personally meaningful

System 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 modelling is extensive (Louca and Zacharia, 2012), concerns have recently been raised about the narrow conceptions of what counts as modelling, how modelling is assessed and how modelling research is framed. Schwarz et al. (2022) argue that modelling as curriculum and modelling as research are often done in ways that do not consider the utility of the practice for students. For example, positioning the creation of a model as the end goal of an activity may provide a window into how students conceptualise an issue, but it strips modelling of the epistemic power that allows students to construct new understandings of phenomena (Schwarz et al., 2022). In these instances, modelling is more meaningful to evaluators than to the students we ultimately hope to support.

Although difficult to capture, the entanglement of modelling practice with learners' histories, goals and social contexts must be considered when deciding what modelling should look like and how it should be assessed (Berland et al., 2016). For instance, Kirk et al. (2023) found that students were more interested in pragmatic actions and societal impacts, and less interested in technical aspects emphasised in science instruction related to socioscientific issues. 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 system modelling as a strategy, students are given a tool to construct such models. As seen across all three sessions, but most clearly in the second session, Sadie and Sam pulled from their personal experiences to engage in sensemaking in a way that meaningfully aligns to them, and, we suspect, to their goals for STEAM 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 on 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

We contend that incorporating societal factors into socioscientific issues-related modelling 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, as well as in society as it currently exists (Morales-Doyle, 2017). Having success with content and skills that are typical gatekeepers to success in science courses and fields is necessary for students 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 at odds, 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 standardised tests (Laughter and Adams, 2012). To build critical consciousness, students need to recognise the complexities and interdependencies of social and scientific issues through engaging in constructive dialogue with diverse perspectives. One 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 system modelling supported students in engaging in socioscientific reasoning through considering multiple perspectives and identifying gaps in their current knowledge. In this way, system modelling is emerging as a strategy for developing sophisticated reasoning skills, which can support academic success.

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

Likewise, the practice of constructing and using these models remains aligned with the *Framework for K–12 Science Education* (NRC, 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 considering two cross-cutting concepts: *systems and system models* and *cause and effect*. Developing modelling competencies has become one of the major goals in science education, and it is a powerful tool for supporting students in science learning (Louca and Zacharia, 2012). In remaining aligned with the NGSS, socioscientific modelling ensures that students can experience academic achievement, a key criterion for JCSP (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 modelling as a concrete tool for teachers implementing a JCSP. 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 Schwarz et al. (2022: 4) have outlined that our field's work on modelling 'is largely based on the European Western scientific canon that values abstracted representational knowledge'. This narrow approach limits opportunities for students to engage in the practice in a manner that acknowledges their contributions to knowledge and culture. Conversely, when learners are encouraged to build from their funds of knowledge, they are free to construct contextualised, personally meaningful connections to the content, making socioscientific modelling a valuable contribution to STEAM education.

Socioscientific system models explicitly identify causal relationships and can better position students to consider complex relationships endemic to SJSIs. Broadening the scope of what can be considered a valid intellectual contribution to a model expands the ways in which students can engage in modelling that aligns with their goals and how they see themselves in relation to science content. By incorporating forms of knowledge and ways of knowing often overlooked in traditional modelling experiences, our participants demonstrated a practice rich with personal knowledge and meaning. Through these affordances, socioscientific modelling is well positioned to create a higher quality, more equitable modelling experience.

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

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Declarations and conflicts of interest

Research ethics statement

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Consent for publication statement

The authors declare that research participants' informed consent to publication of findings – including photos, videos and any personal or identifiable information – was secured prior to publication.

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The authors declare no conflicts of interest with this work. All efforts to sufficiently anonymise the authors during peer review of this article have been made. The authors declare no further conflicts with this article.

References

Aikenhead, G.S. (2006) *Science Education for Everyday Life: Evidence-based practice*. New York: Teachers College Press.

Akom, A.A., Scott, A. and Shah, A. (2013) 'Rethinking resistance theory through STEM education: How working-class kids get world-class careers'. In E. Tuck and K.W. Yang (eds), *Youth Resistance Research and Theories of Change*. Abingdon: Routledge, 153–65.

Amemiya, J., Mortenson, E., Heyman, G.D. and Walker, C.M. (2022) 'Thinking structurally: A cognitive framework for understanding how people attribute inequality to structural causes'. *Perspectives on Psychological Science*, 18 (2), 259–74. [CrossRef] [PubMed]

Bang, M. and Vossoughi, S. (2016) 'Participatory design research and educational justice: Studying learning and relations within social change making'. *Cognition and Instruction*, 34 (3), 173–93. [CrossRef]

Bang, M., Warren, B., Rosebery, A.S. and Medin, D. (2012) 'Desettling expectations in science education'. *Human Development*, 55 (5–6), 302–18. [CrossRef]
Basu, S.J. and Calabrese Barton, A. (2007) 'Developing a sustained interest in science among urban minority youth'. *Journal of Research in Science Teaching*, 44 (3), 466–89. [CrossRef]
Bechtel, W. and Abrahamsen, A. (2005) 'Explanation: A mechanist alternative'. *Studies in History and Philosophy of Science, Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 36 (2), 421–41. [CrossRef] [PubMed]
Berland, L.K., Schwarz, C.V., Krist, C., Kenyon, L., Lo, A.S. and Reiser, B.J. (2016) 'Epistemologies in practice: Making scientific practices meaningful for students'. *Journal of Research in Science Teaching*, 53 (7), 1082–112. [CrossRef]
Bossér, U., Lundin, M., Lindahl, M. and Linder, C. (2015) 'Challenges faced by teachers implementing socio-scientific issues as core elements in their classroom practices'. *European Journal of Science and Mathematics Education*, 3 (2), 159–76. Accessed 1 August 2023. https://files.eric.ed.gov/fulltext/EJ1107835.pdf.
Bråten, I. and Braasch, J.L.G. (2017) 'Key issues in research on students' critical reading and learning in the 21st century information society'. In C. Ng and B. Bartlett (eds), *Improving Reading and Reading Engagement in the 21st Century*. Singapore: Springer Singapore, 77–98. [CrossRef]
Brown, B.A., Boda, P., Lemmi, C. and 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. [CrossRef]
Brown, J.C. (2017) 'A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K–12 settings: Implications for advancing equitable science teaching and learning'. *Journal of Research in Science Teaching*, 54 (9), 1143–73. [CrossRef]
Calabrese Barton, A., Tan, E. and Birmingham, D.J. (2020) 'Rethinking high-leverage practices in justice-oriented ways'. *Journal of Teacher Education*, 71 (4), 477–94. [CrossRef]
Davis, N.R. and Schaeffer, J. (2019) 'Troubling troubled waters in elementary science education: Politics, ethics & Black children's conceptions of water [justice] in the era of Flint'. *Cognition and Instruction*, 37 (3), 367–89. [CrossRef]
Denton, M. and Borrego, M. (2021) 'Funds of knowledge in STEM education: A scoping review'. *Studies in Engineering Education*, 1 (2), 2. [CrossRef]
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. [CrossRef]
Dos Santos, W.L.P. (2009) 'Scientific literacy: A Freirean perspective as a radical view of humanistic science education'. *Science Education*, 93 (2), 361–82. [CrossRef]
Duschl, R. (2008) 'Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals'. *Review of Research in Education*, 32 (1), 268–91. [CrossRef]
Ekborg, M., Ottander, C., Silfver, E. and Simon, S. (2013) 'Teachers' experience of working with socio-scientific issues: A large scale and in depth study'. *Research in Science Education*, 43 (2), 599–617. [CrossRef]
Freire, P. (2018) *Pedagogy of the Oppressed: 50th anniversary edition*. New York: Bloomsbury.
Freire, P. and Macedo, D. (1987) *Literacy: Reading the word and the world*. South Hadley, MA: Bergin & Garvey.
Friedrichsen, P.J., Ke, L., Sadler, T.D. and Zangori, L. (2021) 'Enacting co-designed socio-scientific issues-based curriculum units: A case of secondary science teacher learning'. *Journal of Science Teacher Education*, 32 (1), 85–106. [CrossRef]
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), 610–32. [CrossRef]
Gayford, C. (2002) 'Controversial environmental issues: A case study for the professional development of science teachers'. *International Journal of Science Education*, 24 (11), 1191–200. [CrossRef]
Grotzer, T.A. (2012) *Understandings of Consequence: Learning causality in a complex world.* Lanham, MD: Rowman & Littlefield Education.
Grotzer, T.A. and Tutwiler, S.M. (2014) 'Simplifying causal complexity: How interactions between modes of causal induction and information availability lead to heuristic-driven reasoning'. *Mind, Brain, and Education*, 8 (3), 97–114. [CrossRef]
Hanisch, S. and Eirdosh, D. (2021) 'Causal mapping as a teaching tool for reflecting on causation in human evolution'. *Science & Education*, 30 (4), 993–1022. [CrossRef]

Hmelo-Silver, C.E., Marathe, S. and Liu, L. (2007) 'Fish swim, rocks sit, and lungs breathe: Expert–novice understanding of complex systems'. *Journal of the Learning Sciences*, 16 (3), 307–31. [CrossRef]
Kahn, S. and Zeidler, D.L. (2016) 'Using our heads and HARTSS*: Developing perspective-taking skills for socioscientific reasoning (*Humanities, ARTs, and Social Sciences)'. *Journal of Science Teacher Education*, 27 (3), 261–81. [CrossRef]
Ke, L., Sadler, T.D., Zangori, L. and Friedrichsen, P.J. (2021) 'Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues'. *Science & Education*, 30 (3), 589–607. [CrossRef]
Kirk, E.A., Romine, W.L., Sadler, T.D., Elsner, J.N., Zangori, L.A. and Ke, L. 2023. 'Interest and effort: Exploring the relationship between students' COVID-19 interest and information seeking behaviour'. *International Journal of Science Education, Part B: Communication and Public Engagement* [Paper submitted for publication].
Ladson-Billings, G. (1995) 'But that's just good teaching! The case for culturally relevant pedagogy'. *Theory Into Practice*, 34 (3), 159–65. [CrossRef]
Ladson-Billings, G. (2000) 'Fighting for our lives: Preparing teachers to teach African American students'. *Journal of Teacher Education*, 51 (3), 206–14. [CrossRef]
Ladson-Billings, G. (2006) 'From the achievement gap to the education debt: Understanding achievement in U.S. schools'. *Educational Researcher*, 35 (7), 3–12. [CrossRef]
Ladson-Billings, G. (2009) *The Dreamkeepers: Successful teachers of African American children*. Hoboken, NJ: John Wiley.
Laughter, J.C. and Adams, A.D. (2012) 'Culturally relevant science teaching in middle school'. *Urban Education*, 47 (6), 1106–34. [CrossRef]
Lazarowitz, R. and Bloch, I. (2005) 'Awareness of societal issues among high school biology teachers teaching genetics'. *Journal of Science Education and Technology*, 14 (5), 437–57. [CrossRef]
Lee, H., Abd-El-Khalick, F. and Choi, K. (2006) 'Korean science teachers' perceptions of the introduction of socio-scientific issues into the science curriculum'. *Canadian Journal of Science, Mathematics and Technology Education*, 6 (2), 97–117. [CrossRef]
Lipman, P. (2004) *High Stakes Education: Inequality, globalization, and urban school reform*. London: Psychology Press.
Louca, L.T. and Zacharia, Z.C. (2012) 'Modelling-based learning in science education: Cognitive, metacognitive, social, material and epistemological contributions'. *Educational Review*, 64 (4), 471–92. [CrossRef]
McGee, E. (2021) *Black, Brown, Bruised: How racialized STEM education stifles innovation*. Cambridge, MA: Harvard Education Press.
McGee, E. and Bentley, L. (2017) 'The equity ethic: Black and Latinx college students reengineering their STEM careers toward justice'. *American Journal of Education*, 124 (1), 1–36. [CrossRef]
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.
Moll, L.C., Amanti, C., Neff, D. and Gonzalez, N. (1992) 'Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms'. *Theory Into Practice*, 31 (2), 132–41. [CrossRef]
Moll, L.C. and Greenberg, J.B. (1990) 'Creating zones of possibilities: Combining social contexts for instruction'. In L.C. Moll (ed.), *Vygotsky and Education: Instructional implications and applications of sociohistorical psychology*. New York: Cambridge University Press, 319–48.
Morales-Doyle, D. (2017) 'Justice-centered science pedagogy: A catalyst for academic achievement and social transformation'. *Science Education*, 101 (6), 1034–60. [CrossRef]
Morales-Doyle, D. (2018) 'Students as curriculum critics: Standpoints with respect to relevance, goals, and science'. *Journal of Research in Science Teaching*, 55 (5), 749–73. [CrossRef]
NGSS (Next Generation Science Standards) Lead States. (2013) *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies of Science.
NRC (National Research Council). (2012) *A Framework for K–12 Science Education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
Rodriguez, A.J. (2015) 'What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards'. *Journal of Research in Science Teaching*, 52 (7), 1031–51. [CrossRef]
Rosebery, A.S., Warren, B. and Conant, F.R. (1992) 'Appropriating scientific discourse: Findings from language minority classrooms'. *The Journal of the Learning Sciences*, 2 (1), 61–94. [CrossRef]

Ryder, J. and Banner, I. (2011) 'Multiple aims in the development of a major reform of the national curriculum for science in England'. *International Journal of Science Education*, 33 (5), 709–25. [CrossRef]

Sadler, T.D., Barab, S.A. and Scott, B. (2007) 'What do students gain by engaging in socioscientific inquiry?'. *Research in Science Education*, 37 (4), 371–91. [CrossRef]

Schwarz, C.V., Ke, L., Salgado, M. and Manz, E. (2022) 'Beyond assessing knowledge about models and modelling: Moving toward expansive, meaningful, and equitable modelling practice'. *Journal of Research in Science Teaching*, 59 (6), 1086–96. [CrossRef]

Smith, T., Avraamidou, L. and Adams, J.D. (2022) 'Culturally relevant/responsive and sustaining pedagogies in science education: Theoretical perspectives and curriculum implications'. *Cultural Studies of Science Education*, 17 (3), 637–60. [CrossRef] [PubMed]

Soemer, A. and Schiefele, U. (2019) 'Text difficulty, topic interest, and mind wandering during reading'. *Learning and Instruction*, 61, 12–22. [CrossRef]

Strømsø, H.I., Bråten, I. and Britt, M.A. (2010) 'Reading multiple texts about climate change: The relationship between memory for sources and text comprehension'. *Learning and Instruction*, 20 (3), 192–204. [CrossRef]

Treagust, D.F., Won, M., Petersen, J. and Wynne, G. (2015) 'Science teacher education in Australia: Initiatives and challenges to improve the quality of teaching'. *Journal of Science Teacher Education*, 26 (1), 81–98. [CrossRef]

Trinidad, A.M. (2011) 'Sociopolitical development through critical indigenous pedagogy of place: Preparing Native Hawaiian young adults to become change agents'. *Hulili: Multidisciplinary research on Hawaiian well-being*, 7, 185–221.

Underwood, J. and Mensah, F. (2018) 'An investigation of science teacher educators' perceptions of culturally relevant pedagogy'. *Journal of Science Teacher Education*, 29 (1), 1–19. [CrossRef]

Wilensky, U. and Jacobson, M.J. (2014) 'Complex systems and the learning sciences'. In R.K. Sawyer (ed.), *The Cambridge Handbook of the Learning Sciences*. 2nd ed. Cambridge: Cambridge University Press, 319–38. [CrossRef]

Yoon, S.A. (2018) 'Complex systems and the learning sciences'. In F. Fischer, C.E. Hmelo-Silver, S.R. Goldman and P. Reimann (eds), *International Handbook of the Learning Sciences*. 1st ed. Abingdon: Routledge, 157–66.

Zeidler, D.L. (2014) *Socioscientific Issues as a Curriculum Emphasis: Theory, research and practice*. Abingdon: Routledge.

Zeidler, D.L. (2016) 'STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response'. *Cultural Studies of Science Education*, 11 (1), 11–26. [CrossRef]

Zeidler, D.L., Sadler, T.D., Simmons, M.L. and Howes, E.V. (2005) 'Beyond STS: A research-based framework for socioscientific issues education'. *Science Education*, 89 (3), 357–77. [CrossRef]