ENGAGING IN SOCIALLY RESPONSIBLE SCIENCE EDUCATION (SRSE): PROFESSIONAL DEVELOPMENT OF SECONDARY SCIENCE TEACHERS THROUGH A LEARNING STUDY APPROACH

by

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Abstract

In the revised provincial curriculum, secondary school science teachers in British Columbia, Canada, are expected to prepare students to critically understand and address socioscientific issues (SSI). SSI are issues pertaining to science and society that highlight risks and uncertainties in their development. Despite this new curricular initiative, professional development necessary to support these goals and teacher accounts detailing its actualization in classrooms remains limited. This study aims to support science educators (and, in turn, their students) in creating more just and sustainable futures through what I call socially responsible science education or SRSE.

A 30-week professional development approach – a Learning study – was implemented to support and study four secondary teachers' learning experiences toward SRSE. A Learning study is a collaborative action research variant that distinguishes itself through an explicit focus on theoretical perspectives. These perspectives help structure teachers' classroom research, acting as a lens through which they collaboratively plan, enact, and evaluate classroom practices. In this work, Sjöstrom et al.'s (2017) *Three Visions of Scientific Literacy Heuristic* (3-VSL) was drawn on to frame participants' engagement in the Learning study.

Data sources included transcripts of teachers' semi-structured interviews conducted before and after the study (n=8), audio-video recordings of Learning study meetings (n=26), lesson observations (n=22), and artifacts of teachers' work (e.g., lesson plans). Sixty hours of audio-video recordings were transcribed and analyzed.

By borrowing phenomenographic perspectives, I constructed three qualitatively different ways participants understood, enacted, and developed strategies to pursue SRSE. The description of the categories included several ways the teachers overcame challenges faced in SRSE. This

study provides practical examples of SRSE approaches and illustrates how they might be effectively employed to support teachers' evolving ideas, their classroom practice, and enrich students' learning. The results showcase teacher and professional development attributes essential for SRSE adoption, offering considerations for teacher professional learning and development.

This work makes novel contributions to teacher and science education scholarship. The 3-VSL is unique in Learning study literature – its employment supported the teachers in building and shifting their science education beliefs and practices towards action-oriented and emancipatory outcomes.

Lay Summary

In the revised provincial curriculum, secondary school science teachers in British Columbia, Canada, are expected to prepare students to critically understand and address socioscientific issues (SSI). SSI are issues pertaining to science and society. Despite this new curricular initiative, professional development necessary to support these goals and teacher accounts detailing its actualization in classrooms remains limited.

Based on a 30-week professional development program, four secondary teachers' learning experiences toward socially responsible science education, or SRSE, are explored. Borrowing phenomenographic perspectives, three qualitatively different ways participants understood, enacted, and developed strategies to pursue SRSE are presented. The results highlight practical examples of several SRSE approaches and teacher and professional development attributes essential for SRSE adoption. In the context of rising socioscientific issue-based harms, the implications of this research aim to support science educators and students in creating more just and sustainable futures.

Preface

I was responsible for all aspects of identification, design, implementation, and analysis of the research.

Chapter 2. Portions of Chapter 2 have been previously published [Fuchs, T. T., & Tan, Y. S. M. (2022). Frameworks supporting socially responsible science education: opportunities, challenges, and implementation. *Canadian Journal of Science, Mathematics and Technology Education*, *22*(1), 9–27. https://doi.org/10.1007/s42330-022-00200-x; Fuchs, T.T. (2023). A framework for climate change education in critical geography. *Geography, 108*(2), 95–100. https://doi.org/10.1080/00167487.2023.2217632]. I was the lead investigator, responsible for all major areas of concept formation, data collection and analysis, as well as manuscript composition. Tan, Y.S.M, as my dissertation supervisor, was involved in the early stages of concept formation and contributed to manuscript edits.

Chapter 5. Portions of Chapter 5 have been previously published [Fuchs, T.T. (2023). A framework for climate change education in critical geography. *Geography, 108*(2), 95–100. https://doi.org/10.1080/00167487.2023.2217632].

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To all those belittled and disparaged by school science
And to all those knowing it can do more

Chapter 1. Introduction

In this chapter, the central educational issues, research questions, and study context are presented. A brief explanation of the methodology and methods employed are also provided. The chapter concludes with an overview of the thesis.

1.1 Introduction, Socially Responsible Science Education, and the Educational Issue

Globally connected and locally specific challenges stimulate new ideas for science education (Aikenhead, 2022; Allchin, 2021; Bencze et al., 2020; Hodson, 2011; Levinson, 2018a). One response to these challenges has been the development of approaches to school science that seek to foster social responsibility in learners (Fuchs & Tan, 2022; Onwu, 2017). These approaches encourage students to take a critical stance towards the products of science and technology while empowering them to actively reduce any harm these products may have on individuals, societies, and environments. These approaches go by many names in science education literature but commonly assume that developing social responsibility is a central purpose of contemporary science education. In this dissertation, I have labelled these approaches as socially responsible science education or SRSE.

In SRSE, learners are guided to view themselves as members of society who would employ their understanding of scientific concepts and processes to issues that affect their lives, culture, and the environment, as a means of caring for themselves, others, and their community. These issues are typically termed 'socioscientific issues' (Zeidler, 2014) or SSI. SSI highlight scientific uncertainties in their development and social risks in their impact (e.g., aspects of the climate crisis) (Fuchs, 2023; Levinson, 2018b).

Echoing the claims of SRSE is British Columbia's (BC) revised provincial science curriculum. Science education is expected to develop students’ ability to bring scientific perspectives to bear on “social, moral, and ethical decisions and actions in their own lives, culture, and the environment” (BCME, 2018a). This vision for science education (Roberts, 2011) is argued for by numerous researchers, citing its potential to increase students’ scientific understandings (Kinslow et al., 2018), to invite more learners to pursue science-related interests (Steele, 2016), including careers (Hofstein et al., 2011), and to ensure all members of society are scientifically literate (Bencze, 2017; Hodson, 2011; Sjöström et al., 2017). However, these aims and curricular mandates are easier justified than implemented (Hodson, 2013): many Canadian science teachers are hesitant to view science education as a means for social change (Hoeg et al., 2017; Pedretti & Bellomo, 2013), and professional development initiatives in this area are often marred in challenges (Bencze, 2017; Gray & Bryce, 2006).

Science teachers' viewing science education as a means for social change typically requires several mutually-supportive conditions (Bencze et al., 2018), including a personal philosophical approach to teaching that is often different from what most science teachers encountered in their own science education (Aikenhead, 2006; Pedretti & Nazir, 2011). This educational issue relates to the false dichotomy held by many science educators (Cross & Price, 1996), where they might feel inclined to choose between "teaching for socio-scientific decision-making and conceptual understanding" (Sadler et al., 2006, p. 373).

In BC, the revised curriculum supports dispelling the dichotomy (as shown above and will be elaborated upon later). However, in doing so, it still sets a new imperative for science education in which science teachers have to think differently about their practice. Coupled with the limited curricular guidance in translating SRSE-aligned expectations to practice (e.g., BCME, 2022a; BCME, 2022b; Blades, 2019), it is clear that teachers need further support.

Teacher professional development is a common support mechanism for curricular changes and new ideas in educational research (Borko, 2004; Darling-Hammond & McLaughlin, 1995). However, regarding SRSE, challenges arise regarding the type of professional development provided (e.g., Fuchs & Tan, 2022). As an example, the typical seminar or one-day professional development approaches favoured for their 'efficient' and 'succinct' deliveries (e.g., BCScTA, 2023) – while also being abjectly favoured by some members of the profession for the reduced time teachers have to be away from schools (Mockler, 2013; Roseler & Dentzau, 2013) – are often ineffective to stimulate long term changes in practice (Elmore, 2002; Mitchell, 2013). This is especially salient given the other educational issue addressed in this study: that teachers pursuing SRSE approaches face particular pedagogical challenges (e.g., Can et al., 2017; Chen & Xaio, 2021; Tidemand & Nielson, 2017) and such challenges that are difficult to address in short time periods (e.g., consistently moving away from lecture formats to favour self-directed student exploration [Lee & Yang, 2019]).

Surprisingly, given the need yet understandable difficulty of SRSE approaches, limited empirical research has explored teachers' understandings, enactment, and long-term professional development experiences pursuing this approach to science education, especially in contexts in which it is explicitly promoted (cf. Bencze, 2017; Pedretti & Bellomo, 2013). Without a thorough analysis of science teachers' understandings, practices, and professional development experiences related to SRSE, the potential roles that science teachers, teacher educators, and the science education community might play in addressing humanity's most pressing challenges (e.g., climate change, environmental degradation, social inequality) remains under-explored. This leaves young people without the necessary support to develop their ability to engage with complex SSIs critically and leaves teachers, teacher educators, administrators, and professional development leaders with limited evidence-based theories and practices to guide their work. Given humanity's pressing socioscientific challenges and their potentially disastrous impact (Ord, 2020), those involved in science education must have the required resources and preparation to comprehend and confront how science education contributes to and can even alleviate some of these challenges (Aikenhead, 2022; Bencze, 2020). By implementing a professional development program, I aim to address and explore key pedagogical and professional development issues underpinning teaching and learning to teach SRSE.

1.2 The Professional Development Approach, Research Questions, and Purpose of the Study

The professional development approach I will draw upon is Learning study (Pang & Marton, 2003). Simply, it aids teachers in exploring educational issues they care about through teacher inquiry in their own classrooms. The research involves iterative cycles of collaborative lesson planning, teaching, and reflection that are guided by the employment of select theoretical perspectives. Learning study is helpful in curriculum reform as it encourages evidence-based pedagogy (Ko, 2019a; Wood, 2013), where teachers assess novel strategies and document their findings. This builds a knowledge base of educational hypotheses that can be continually tested and shared (Elliott, 2012). Learning study has been used throughout the world (Hanfstingl et al., 2019) to support teachers in educational reforms, for example, in Hong Kong (Lo, 2009; Pang, 2006), Singapore (Tan & Nashon, 2013), and Canada (Royea & Nicol, 2019). It has also been used extensively in science education contexts (Attorps & Kellner, 2017; Holmqvist & Olander, 2017; Lo et al., 2006; Nilsson & Vikström, 2015; Tan et al., 2019a, 2019b).

As noted above, one of the defining characteristics of Learning study is employing theoretical perspectives as lenses through which teachers explore and address educational aims

(Pang & Marton, 2003; Tan, 2014a). The theoretical perspectives provide teachers with frameworks they can draw on to understand and reflect on their teaching, student learning, and the relationship between the two (Pang & Lo, 2012). While this has benefits for teachers, students, and educational researchers (e.g., Elliott, 2015; Ko, 2019; Wood & Sithamparam, 2015), theoretical perspectives nonetheless limit how and what teachers focus on in their research (e.g., through definitions of learning, teaching, and methods to better the two) (Lo, 2016; Runesson, 2015). There is a need to explore diverse theoretical perspectives in Learning studies to understand their various utility to educators (Runesson, 2016; Tan et al., 2019b).

Concerning theoretical perspectives for the intersection of SRSE and Learning study, *Three Visions of Scientific Literacy Heuristic* (3-VSL) (Sjöström et al., 2017) stands out due to its relevance to science teaching, learning, and organizing educational research (e.g., Bencze et al., 2020; El Halwany et al., 2021; Fuchs & Tan, 2022; Harding & Fuchs, 2021; Rasa et al., 2022; Schaffer & El Halwany, 2020; Zindy et al., 2020). While the purposes of school science have been debated in the literature (DeBoer, 2000; Layton, 1972; Roberts, 2011), following Hodson (2011), I argue that the various purposes attributed to school science can be mapped along a continuum that underpins 'scientific literacy.' This is consistent with Sjöström et al.'s (2017) conceptualization of scientific literacy (3-VSL), which includes three essential literacies: conceptual, contextual, and critical. Each has different yet connected foci. Respectively, these include a focus on internal processes of science for future courses and careers in science, external processes of science for societal participation, and ensuring the wellbeing of consumers and producers of science through individual/group transformations and actions.

Each of these components of scientific literacy builds and supports each other (Hodson, 2011; Sjöström et al., 2017). In relation to SRSE, each Vision is recognized as important.

However, responding to many of the world's challenges takes a specific interest in the critical literacy area (Hodson, 2011). As such, SRSE is an approach to science education that is "self-involving *and* socially just [emphasis added]" (Sinnes et al., 2011, p. 2). This definition of SRSE, buttressed by the 3-VSL, is intended to aid teachers in their exploration of scientific literacy through the Learning study discourse. This area will be further explored in Chapter 2 when the theoretical perspectives of 3-VSL presented in the Learning study are explained.

In light of the potential of a 3-VSL-framed Learning study, the research undertaken in this dissertation investigates how BC secondary science teachers' participation in a 3-VSL-framed Learning study influences their learning and pedagogy. The overarching research question is: **How did high school science teachers participating in a 3-VSL-framed Learning study understand and enact SRSE?** The following guiding questions were formulated to aid in the investigation of the overarching research question:

(1) What different approaches did participating teachers develop to teach socioscientific issues in their classroom settings?

(2) What were the perceived challenges participating teachers faced while teaching socioscientific issue-based lessons?

(3) What strategies did the participating teachers develop to tackle challenges faced in teaching socioscientific issues?

My position is that curricular documents, association statements, and calls from research advocating SRSE by teachers are not platitudes but serious considerations for students' present and future wellbeing. SRSE is part of a diverse science education program, and this diversity has the potential to impact more students, develop more learning domains, and positively influence the human and more-than-human worlds that students inhabit.

With this ethos and research questions, I seek to explore some challenges teachers encounter when enacting SRSE. I aim to add to the literature seeking to support science teachers in implementing critically minded, community-oriented, and SSI-driven goals for science education. I aim to explore how science teachers understand, enact, and work through challenges associated with SRSE in classroom contexts when supported by a 3-VSL-framed Learning study.

1.3 Context of Study in Science Education and British Columbia

While neither novel (Sadler, 2009, 2011) nor without critique (Hadzigeorgiou, 2015), compelling cases are made for science curriculum seeking to develop the capacity for students to understand, make personal decisions, and act to resolve complex SSIs. Authors have empirically demonstrated its potential to increase students' general scientific understandings (Endreny, 2010; Kinslow et al., 2018), nature of science competencies (Khishfe et al., 2017), communication skills (Chung et al., 2016), and activism potential (Roth & Lee, 2004; Schindel Dimick, 2016).

Socioscientific reasoning skills (Sadler et al., 2007) act as a measure to "describe thinking practices that individuals use as they make sense of, consider solutions for, and work to resolve complex SSIs" (Romine et al., 2017, p. 276). Several studies have documented the benefits to students through these thinking practices based on exploring SSIs (Kinslow et al., 2018). For example, the SSI of obesity was explored in Leung & Cheng's (2020) study of 114 undergraduate students. Based on a socioscientific teaching and learning model (Sadler et al., 2017), its exploration improved students' SSI perspective-taking abilities (e.g., Kahn & Zeidler, 2016). Students demonstrated an ability to consider a broader range of perspectives when explaining the determinants of obesity. The authors noted a particular increase in the use of factors related to societal and environmental influences on food production and consumption rather than more ignoble narratives about obesity being 'self-inflicted.' The ability to value others' perspectives and understand arguments from those perspectives has also been improved in secondary school students with similar SSI-focused approaches (e.g., Chung et al., 2016).

In Lee et al.'s (2013) study on 132 secondary school students, the SSI of gene modification was explored. The authors found that the students became more aware of scientific developments' moral and ethical considerations and more empathetic towards those directly and indirectly affected. Eastwood et al.'s (2012) study of over 90 secondary school students found that the social and cultural aspects of the scientific enterprise were more easily discerned when receiving instruction based on SSIs (in this case, those related to an Anatomy and Physiology course, such as fluorinated water, alcohol, and marijuana consumption), than a purely content-driven curricular sequence. The positive influence of SSIs as a context for students and teachers to learn about the scientific enterprise's subjective, social, and tentative nature has been reported in other empirical work (e.g., Khishfe, 2014; Leung, 2020; Wong et al., 2011).

Further, complex SSIs can be studied through local, place-based science education (Burek & Zeidler, 2015; Roth & Lee, 2004). In these approaches, specific SSIs are chosen that are relevant to the local area. This learning method is effective in helping students understand scientific concepts and make personal decisions about these issues (Endreny, 2010; Schindel Dimick, 2016).

Herman et al. (2018) and Herman et al. (2019) studied 60 secondary students who learned about a specific SSI related to wolf reintroduction in Yellowstone National Park. They found that the students developed a stronger compassion towards people and nature affected by SSIs and a desire to address them. These findings align with the results of Lee et al. (2013), who found after three weeks of lessons on the impacts of gene modification and editing, students felt more responsible for addressing related SSIs. The above finding echoes similar SSIs and placed-based work regarding an urban park restoration project (Schindel Dimick, 2016).

The studies reviewed show that leveraging SSIs congruent with SRSE benefits student learning. That said, research also forwards caution when science educators emphasize science's role in society or citizenship. For example, 'critical' science education often supposes that change is necessary, while preserving and rejuvenating extant practices in many communities may be as important (Bigloo et al., 2021; Bowers, 2008). As Hadzigeorgiou (2015) noted, prioritizing sociopolitical action in science education may also shift the focus from a meaningful learning experience to a formulaic activity. Here, students' sense of wonder and curiosity may not be given enough time to develop in favour of "go-ask-find-and-use" (p. 276) activities. Finally, incorporating scientific concepts in examining social issues can convey a preferential status to scientific knowledge and epistemologies (Aikenhead, 2007). On the one hand, this approach may involve misusing principles and frameworks developed for closed rather than open and complex systems (Levinson, 2018a). On the other, it can disparage other knowledge systems and worldviews. Despite this, the evidence presented in this section challenges the commonly held belief among many school science teachers that choosing between socioscientific decision-making and conceptual understanding is necessary. Much of the research cited above demonstrates that both these goals can be achieved and strengthened by cultivating students' ability to critically understand and address SSIs.

Aside from student learning evidence, research also alludes to the potential connections between science education focusing on social responsibility and science teacher recruitment (Fuchs et al., 2022). Dwindling recruitment and retention numbers of science teachers in North America and elsewhere are a concern (Gore et al., 2017; Gist et al., 2019; Han et al., 2018).

However, many prospective teachers and science teachers seek to join the profession to contribute care to their students and communities (Christensen et al., 2019; Gore et al., 2016; Lai et al., 2005; Smith et al., 2004; Van Rooij et al., 2020). Infusing these ideals more explicitly in teachers' classroom activities is one way to position curriculum (e.g., with SRSE) as a recruitment and retention tool (Fuchs et al., 2022).

Finally, taking a normative route, other authors argue that more active and critical stances of science education will prepare students to be fully engaged citizens (Hodson, 1999; Hofstein et al., 2011), capable of not only understanding scientific issues in society but emboldened with the capacity to act morally and ethically to reduce potential harms the issues may cause. Focusing on Western Canada, Trans Mountain pipeline debates (McCarthy et al., 2019), climate marches/protests (Mortillaro, 2019), privatization of health care (Conrad & Mitchell, 2023), and pandemic control measures (McElroy, 2020) exemplify local SSIs that need to be discussed and addressed by the whole citizenry, including science students, who through their scientific studies can bring increased awareness and diverse perspectives to possible solutions. SSIs' rising prevalence and potential negative consequences (Leonard, 2010; Steffen et al., 2018) are unlikely to abate if socially just action is not undertaken (Bencze & Carter, 2011).

Given the above evidence connecting student learning, teacher recruitment, and citizenship goals, it is unsurprising that SRSE has made its way into recent science teacher association periodicals (Mackenzie, 2020) as well as national (Onwu, 2017) and provincial (Blades, 2019) curricula. In Canada, the present social, political, and environmental milieu provides science educators with tremendous opportunities to explore what it means for science education to be socially responsible (e.g., GoC, 2019; TRC, 2015) through these curricular avenues.

In the Canadian province of BC, where this study is located, recent science curriculum reform echoes many potential goals of SRSE as described above in Section 1.1 (e.g., BCME, 2018a). In addition to this curricular statement, two new courses, Environmental Science 11 and 12 and a revamped Science for Citizens 11, provide specific courses where social and environmental responsibility are a focus (Blades, 2019).

Buttressing these courses and curricular aims are other features of the revised BC curriculum (Fuchs & Tan, 2022). It contains approaches which support the development of SRSE fully integrated into curricular documents rather than treating them as add-ons (Hodson, 2003), as seen in some other Canadian provinces (Tippet & Milford, 2019). These include the removal of vital systemic barriers related to curriculum mandates (Bencze, 2017) (e.g., BC favours competencies over content), explicitly prioritizing practices which promote SRSE, such as student-directed and open-ended research (Hodson, 2011; Pedretti & Nazir, 2011), and the reinforcement of curriculum goals with appropriately aligned assessment practices (Fuchs & Tan, 2022; Tidemand & Nielson, 2017).

However, while including SRSE in science teacher periodicals and curricular documents should be lauded, it nevertheless produces new challenges for teachers, researchers, and professional development leaders (Chen & Xiao, 2021; Pedretti & Bellomo, 2013; Hodson, 2013). Many science teachers feel unable to adopt contextual and critical scientific literacy approaches in their classrooms, both in Canada (Pedretti & Bellomo, 2013) and elsewhere (Tidemand & Nielsen, 2017), due to a lack of mentorship in how to critique and adapt such ideas to various contexts (Aikenhead, 2006). This is exacerbated by external factors such as reduced resources and limited time to engage in teacher professional development (Mockler, 2013; Roseler & Dentzau, 2013). Furthermore, some science teachers may be hesitant to view science education as a conduit for social change (Chen & Xiao, 2021; Pedretti & Bellomo, 2013; Sadler et al., 2006) due to personal, collegial, or systemic factors. These factors have incredible breadth, including a hesitancy to explore science education's role in perpetuating and addressing anti-black racism (Watson et al., 2018), a lack of pedagogical familiarity or interest (Cheng & Xaio, 2021; Lee & Yang, 2019), or collegial support (Can et al., 2017). These challenges have been referred to by some researchers as an 'invisible hand' (Bencze, 2017) upholding more traditional science education practices, with one inhibitor often replacing another as it is addressed.

In BC, teachers may likewise need support teaching the SRSE-related components of the revised curriculum for the reasons mentioned above. However, while the revised curriculum provides some guidance, it nonetheless has its challenges. One is that the SRSE components of the revised BC curriculum are often embedded within core competencies (i.e., broad competencies like 'social awareness and responsibility' that unite the entire curriculum) rather than appearing explicitly as content. These competencies may be overlooked because they are novel in the revised curriculum. Additionally, while the content of the curriculum is mainly unchanged from previous versions, there are new additions in several science courses (Blades, 2019). This could lead teachers to prioritize content based on familiarity or as a "list of topics [they] should be teaching" (Blades, 2019, p. 33) rather than focusing on the skill and process-oriented competencies that are meant to underpin content knowledge acquisition. Finding the balance between curricular support and teacher autonomy is not novel in science education (Aikenhead, 2006). However, the revised curriculum provides significantly less guidance, summarizing a course in only two pages compared to 30 pages in previous curricular iterations. This places greater responsibility for curricula and pedagogical decisions on teachers.

As a result, while secondary school teachers in BC may recognize the value of science education approaches that align with SRSE for both pedagogical and sociopolitical reasons (as seen in other jurisdictions [Bencze, 2017; Sadler et al., 2006; Tidemand & Nielsen, 2017]), their ability to effectively implement these approaches based on curricular mandates alone is limited in BC. Curricular mandates are essential but generally insufficient to fully support changes in teacher practice (Gu & Wang, 2006; Hodson, 2003), and this is true for SRSE approaches (Krstovic, 2017). The open-ended, value-laden, and often unfamiliar pedagogies and knowledge bases required for SRSE (Pedretti & Nazir, 2015) are difficult to master with just curricular guides or one-off professional development opportunities (Elmore, 2002). This study aims to address these difficulties by considering the challenges teachers face in teaching science education from an SRSE-oriented perspective, the lack of BC curricular guidance, and the prevalent professional development models in BC.

1.4 A Brief Description of Methodology and Methods

In this research, I am interested in how teachers' participation in a Learning study has helped develop their understanding, insights, enactment and reflection of SRSE. Data were drawn from four teachers engaged in the Learning study exploring SRSE over a 30-week period. Data came from transcripts of individual teachers' semi-structured interviews conducted at the beginning and end of the study (n=8, 10.75 hours total, transcribed verbatim), audio-video recordings of all meetings (n=27, 27.75 hours total, transcribed verbatim), lesson observations (n=22, 21 hours total, field notes and audio-video recordings), and artifacts of teachers' work (lesson plans, handouts, PowerPoint presentations).

Document collection (including meeting notes, emails, and handouts prepared by the researcher) recorded the flow of the Learning study, serving as a record of what was intended and what occurred during all interactions with teacher participants. Field notes (including a researcher journal) captured evolving ideas, articulating my own before, during, and after understandings of the Learning study, and more general introspection to practice reflexivity (Guba, 1981). All sources served as rich objects for data triangulation.

Given my interest in the range of teachers' collective experiences and the relationships between them, a largely phenomenographic approach (Marton, 1981, 1986; Marton & Booth, 1997; Tan & Caleon, 2022) was employed for data analysis. After initial transcription and the marking and collating of data sources, individual teacher profiles were developed through a narrative account of their experiences in the Learning study. The descriptions were a complete rendering of each teacher's 30-week participation. This provided contextual details for the remaining analysis. The outcome of the analysis was three qualitatively different ways the teachers experienced approaching SRSE.

By drawing from phenomenographic perspectives and employing a 3-VSL-framed Learning study to support and research teachers' experiences, this dissertation adds to an emerging literature exploring inquiry-based teacher professional development aimed at SRSE approaches (cf. Bencze, 2017). This research expands our knowledge of how teachers understand SRSE and the more general use of SSIs in secondary science classroom contexts. Further, this research shows how teachers learnt about SRSE, including how they overcame perceived challenges in classroom implementation. These learnings are significant as they point to a diverse range of attributes and instructional strategies the teachers developed for successful SRSE enactment that can be theoretically generalized to other situations (e.g., Yin, 2014).

How the Learning study discourse contributed to developing these attributes will also be presented. This is significant as it provides examples of professional development conditions teacher educators can draw on for guidance. For example, this research will provide tangible examples of approaches the participating teachers used to teach SRSE. These can serve as starting points for educators interested in similar work. This point is crucial in BC, given the explicit curricular articulation but limited classroom guidance in translating SRSE-aligned expectations to practice (e.g., Blades, 2019).

More broadly, this dissertation contributes to three intersecting areas of research: science education, teacher professional learning, and Learning study. The study provides insight into how critical SSI-based practices can be supported and implemented in science education. In the field of teacher learning, the study offers novel theoretical insights into the analysis of a 30-week teacher professional development experience. Finally, this research aligns and extends contemporary trends in Learning study literature by exploring the employment of a novel theoretical framework, objects of learning, and a collaborative arrangement that is defined in this study as a 'concurrent-and-successive model.'

1.5 Positionality

My positionality in this research relates to the intersecting areas described above and the educational issues presented. Understanding a researcher's positionality allows methodological, theoretical, and analytic choices to be understood regarding what a researcher brings to the research process (e.g., Dwyer & Buckle, 2009; Kerstetter, 2012). I have provided a more detailed narrative of my own experiences in science, as a learner and then a teacher (see Section 3.8.1), my involvement in various teacher collaborative inquiry groups (see Section 3.8.2), and my grappling with different purposes of school science that resulted in a constant shaping and reshaping of my beliefs, perspectives and conceptions of science teaching and learning (see

Section 3.8.3). These experiences have collectively shaped my positionality both as a researcher and learner.

As a short introduction to myself and my position, I have been a high school and middle school teacher since 2013, and I have experience teaching during times of curriculum reform in Canada. In addition, I have often pursued non-traditional science education practices – many of which align with SRSE (e.g., LGBTQ [as it was called then] inclusivity in the science classroom [Fuchs, 2016]) – and I am familiar with the challenges and opportunities this pursuit can entail. Finally, as a teacher, I have experience attending and designing professional development programs (Fuchs et al., 2021; Harding & Fuchs, 2021).

These experiences engaging with curriculum reform, new approaches to science education, and participating in and designing teacher professional development initiatives inform my methodological choices and shape the research process outlined in this dissertation. For example, I chose to position SRSE as contributing care and addressing harm from SSI. This position has taken over an explicit reference to social justice (e.g., Morales-Doyle, 2017), owing to my experience engaging in this type of work in science classrooms. I recognize the importance of social justice discourse and its significant connections to SRSE (Valladres, 2021), but aimed for a pragmatist orientation based on my own experience of meeting teachers where they are at to explore the potentiality of SRSE further (Bencze, 2017). A complete summary of how I have engaged with my positionality through the research process is found in Section 3.8.

1.6 Thesis Overview

In this chapter, I provided a general overview of SRSE, the educational issue, the professional development approach, and the context of the study. I provided empirical and normative evidence in support of SRSE as well as caveats to highlight that SRSE is only part of a diverse school science education program. Nonetheless, I argued SRSE deserves attention given science teachers' unfamiliarity with the approach and its potential to support students in learning about pressing (even dire) SSIs facing society. In Chapter 2, Sjöström et al.'s (2017) *Three Visions of Scientific Literacy Heuristic* is introduced as a theory framing the current study, such as the design of teachers' experiences in the Learning study and the data collection and analysis. The heuristic is also employed as the theoretical framework of the Learning study, where teachers' learning about, discussing, planning, enacting and reflection on their SRSE lessons were guided by the framework. Teachers' perceptions of science education frameworks with similar goals as SRSE are reviewed to showcase the suitability of Learning study more fully in attending to professional development needs. In Chapter 3, phenomenography as a methodological approach is introduced. The Learning study as a professional development approach is then reviewed, including contemporary trends I will directly respond to in this work. This review is used to explicate my own design and implementation of a Learning study, encompassing the study methods and the data collected. The data analysis methods are explained and justified, and how I addressed trustworthiness, reliability, and validity issues are discussed. Chapter 3 closes with a description of my positionally in this research. In Chapter 4, the results are presented, detailing three qualitatively different ways the teachers experienced learning about SRSE in the Learning study. In Chapter 5, I discuss the results, including the phenomenographic characteristics pertinent to the research questions. Chapter 5 is organized around the three specific research questions aforementioned. In Chapter 6, I present the work's conclusions, limitations, and delimitations. This is followed by implications and significance for SRSE practice and supporting future SRSE work, research in teacher learning more generally, and the implementation of future Learning studies.

Chapter 2. Literature Review and Theoretical Framework

In the introduction, I argued that SRSE is an important development for school science education to respond to some pressing SSIs facing our world. I located this argument in the revised BC science curriculum and presented some difficulties associated with supporting SRSE through professional development. After introducing a professional development approach to address these concerns, I drew on empirical research highlighting SRSE's benefits to student learning. I also summarized theoretical arguments extrapolating the effects of such approaches on the well-being of individuals, societies, and environments. From this theoretical and empirical interplay, I presented caveats for SRSE to show that it is one piece of a diverse school science education program. I argued that SRSE should *not* be the only approach employed but that more diversity in school science approaches is needed. Greater diversity can impact more students, develop more learning domains, satisfy more teachers' career aspirations, and positively influence the broader biotic and abiotic school community. BC, as the study context, was then discussed. BC is unique in that its revised curriculum has approaches which support SRSE throughout. However, teachers still have difficulties in teaching science education from an SRSE-oriented perspective, and the prevalent professional development models in BC are unlikely to produce sustained changes in practice. Given its curricular support, BC is an ideal location to study the different ways teachers understand and enact SRSE, the challenges and opportunities teachers face when doing so, and the strategies pursued in its adoption.

In the following chapter[1], I introduce a *Three Visions of Scientific Literacy Heuristic* (3-VSL) (Sjöström et al., 2017) to briefly track some of the goals of science education pertaining to

[1]This chapter is based on an article first published in the *Canadian Journal of Science, Mathematics and Technology Education* by Springer Nature (Fuchs & Tan, 2022). It is being reproduced with permission from Springer Nature. The chapter is an extension of that work, updated where appropriate and extended to foreground the remaining chapters of this dissertation.

SRSE. As described in Section 1.2, I conceptualize SRSE as containing all Visions while still leaning toward Vision III. I examine four established frameworks with similar goals. These include Science-Technology-Society-Environment education (Pedretti & Nazir, 2011), Socioscientific Issues-based education (Sadler, 2011; Zeidler, 2007), Critical Pedagogy of Place (Gruenewald, 2003), and Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments (Bencze, 2017). Following, I review opportunities and challenges teachers feel are associated with the frameworks' implementation and use the review to provide implications for interventions. From these implications, I introduce Learning study as a professional development model that has the potential to promote the adoption of SRSE practices. Since the Learning study is part of my methods, I save the history and development of Learning study for later chapters. To close Chapter 2, I discuss two theoretical perspectives from the 3-VSL framework that I used at the level of the researcher and the Learning study participants to frame the study.

2.1 Conceptualizing Socially Responsible Science Education Along Three Visions of Scientific Literacy

Science education seeking to foster social responsibility in learners is not new. Bernal (1949) notes that a science teacher:

> must concern [themselves] with immediate practical social problems … To do less would be to admit that science was just a play of words and would inevitably create in the minds of students the ideas that it was an ineffective adjunct to life, instead of one of the major agents of social change. (p. 143)

Over the following decades, authors build on this argument, examining social responsibility and its connections to science, technology, society curricula (Cross & Price, 1991; Rip, 1978), the

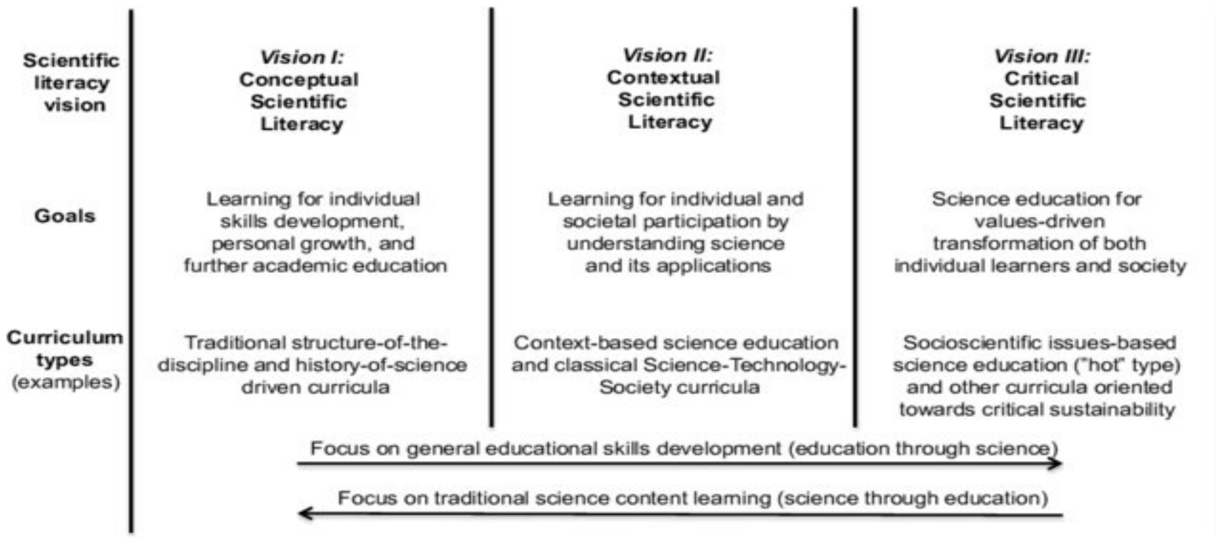
Socioscientific Issues-based framework (Lee et al., 2013), and, recently, science education for responsible citizenship (Evagorou et al., 2020). In all, there is the recognition that science education has a part to play in showing students how they and their societies are "liable for creating and resolving SSI" and that "even small actions will be useful in resolving the issues" (Lee et al., 2013, p. 2103).

How the SSI might be resolved, who/what the resolution is aimed at, and if the focus resides on the individual or broader societal systems depends on the particulars of the science education context (e.g., Cross & Price, 1999). However, a focus on individual and/or social transformations and/or actions remains (Sjöström et al., 2017). Social responsibility in science education encourages learners to take a critical stance towards products of science and technology while also empowering them to reduce the potential harm these products have on individuals, societies, and environments. Though this stance is not new, its increasing mention in policy documents and practitioner discourse remains novel. To understand how this focus developed, I briefly trace some goals of science education through the term scientific literacy by drawing on 3-VSL as conceptualized by Sjöström et al. (2017) (Figure 1).

Since its 1950s inception, the definition of scientific literacy has been hard to pinpoint (DeBoer, 2000; Hodson, 2003). Many authors offer their own definitions, largely based on political leanings and espoused intent of school curriculum (e.g., ACARA, 2012; CMEC, 1997; NRC, 2012). Notably, almost all definitions of scientific literacy recognize it as an essential curriculum goal and therefore use it to describe the overall character of what school science should be about (Aikenhead, 2007; Roberts, 2011). Typically, this produces two foci for school science (Layton, 1972; Roberts, 2007), one concerned with the internal relations of science and one with the external relations. These foci represent Robert's (2007) original contribution and are the first two Visions of Sjöström et al. (2017) heuristic.

Figure 1

Each Vision of scientific literacy in Sjöström et al.'s. (2017) heuristic. The figure from Sjöström et al. (2017) highlights the continuous nature of the Visions in terms of focus on education skills or traditional science content learning. This is despite the Visions distinctions in terms of goals and curriculum types.



In the heuristic[2], Vision I is termed conceptual scientific literacy. It concerns epistemological and conceptual dimensions of science, the correctness of answers, and the development of science-related skills (Roberts, 2011; Sjöström et al., 2017). This vision for school science was largely championed in the post-Sputnik era and used as a pre-professional training pipeline where future scientists could be screened and developed to advance national goals related to economic prosperity and national security (Blades, 2019). This vision aims to support students in becoming future scientists (Aikenhead, 2006; Fensham, 2002; Roberts, 2007), preparing them for future science coursework and careers.

[2]Portions of this section are based on an article first published in *Geography* by Taylor & Francis Online (Fuchs, 2023). It is being reproduced with permission from Taylor & Francis Online. This section is an extension of that work, updated where appropriate and extended to foreground the remaining chapters of this dissertation.

Vision II is termed contextual scientific literacy. It is concerned with applying scientific knowledge as contextualized in students' lives and society (Roberts, 2011; Sjöström et al., 2017). This vision for school science was largely championed following a decrease in student interest in science and science-related careers in the 1970s (Gaskall, 1982), as well as a recognition of science's increasing role in contemporary society (Gallagher, 1971). Here, it was argued that the overt selectivity of post-Sputnik science programs was missing an opportunity for all students to engage in the discipline (Blades, 2019). Today, the majority of students do not pursue formal science studies after school and are unlikely to re-visit the scientific content covered following graduation (Bennet & Hogarth, 2009; Lyons, 2006). As a result, Vision II aims to foster students' pragmatic understandings of the scientific enterprise in sociocultural contexts, supporting all citizens in their potential uses of scientific knowledge (Roberts, 2007).

The internal/external divide presented above remains volatile. For example, following the propulsion of Vision II, there has been a renewed focus on Vision I outcomes through the advent of Science, Technology, Engineering and Mathematics (STEM) education initiatives (Weinstein et al., 2016). Several authors contend this recent focus has regressed the diversity of science education emphases (Steele, 2016; Zeidler, 2016) in what Pierce (2013) describes as the 'neo-Sputnik' model of science education. Here, inter-country competition in economic and military capabilities is again seen as the main driver of science education norms and practices (e.g., Machi, 2009). Critiques, responses, and reformulations of STEM (e.g., adding Arts to produce STEAM) have been forward (Mejias et al., 2021) and will not be redrawn here. What is important is that given the increasing popularity of STEM and its typical Vision I orientation, Vision II and III remain important contemporary considerations for the diversity of science education practices.

Extending the dynamisms of internal/external formulations is Vision III. Termed critical scientific literacy, it is concerned with “science for individual and societal actions and transformations” (Sjöström et al., 2017, p. 182). The concept for Vision III in school science was put forth by individuals who recognized that Vision I and II focused on the importance of specialized professionals and informed citizens using science for the betterment of society. Yet, these ideals were rarely examined fully or actively pursued. Like the critical scientific literacy outlined by Hodson (2011) and the civic scientific literacy outlined by Shen (1975), Vision III aims for science education to have a social-political impact, empowering students to play active roles as engaged citizens (Levinson, 2018a).

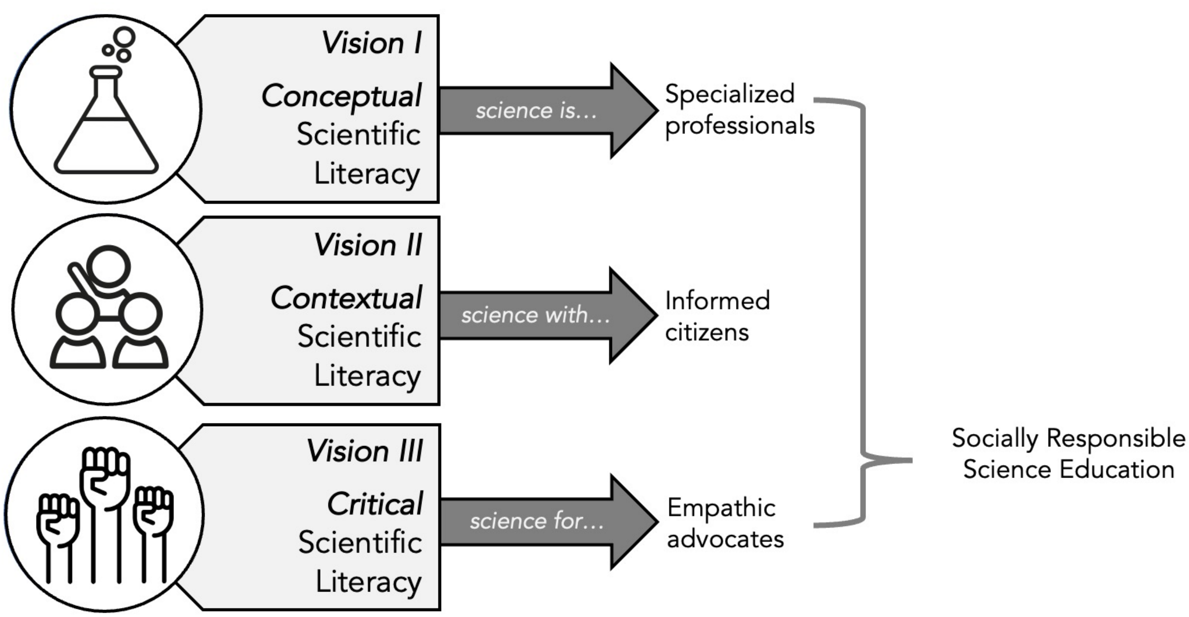
To place in practice these abstract definitions, I will briefly describe the Visions employment in a classroom context through the lens of an SSI: aquaculture. This is summarized in my interpretation of the 3-VSL, as presented in Figure 2. In the vignette, I’ll also draw on Hodson’s (2011) contemporary goals for science education (e.g., students’ learning science [Vision I], doing science [Vision I], learning about science [Vision II], and engaging in socio-political action [Vision III]) to justify conceptualizing SRSE through 3-VSL. Teachers can focus on all the Visions, or a mixing of two, to some degree throughout an academic year (Sjöström et al., 2017). The below vignette simplifies the Visions relations for illustrative purposes.

2.1.1 A Socioscientific Issue Vignette for Socially Responsible Science Education

From a Vision I perspective, aquaculture could be used to initially excite and place in some context a lesson on the nitrogen cycle. Here, the primary focus is on students *learning science* and *doing science* (Hodson, 2011) (e.g., science is …) in relation to the nitrogen cycle so they may become knowledgeable specialized professionals. The SSI chiefly draws students in, acting as a ‘hook’ or an opener for the unit before the nuances of nitrates and nitrites are explored. In contextual literacy, this context is broadened; the SSI provides a scaffold to explore science and its relations with other technological, societal, and environmental areas. Aquaculture could be a stepping-off point to explore how changing nitrate concentrations impact native fish populations and broader food production systems. Here, the SSI is used to facilitate students *learning about science* (Hodson, 2011) (e.g., science with …) so they may become informed citizens. In critical literacy, the SSI provides the impetus to engage students' emotions and the motive to do something with them. After students have explored Vision I and II perspectives (e.g., how and why a change in nitrate concentrations from aquaculture harms native fish populations), they can be invited to do something to address the issue. This might include using the Ocean Wise website (https://ocean.org) to understand where and how more sustainably harvested seafood is sold and sharing locations with the school community. In another project,

Figure 2

Adapted from Sjöström et al. (2017) Three Visions of Scientific Literacy Heuristic, with additions from Hodson (2011) and Roberts (2007, 2011). Visions I, II, and III are presented top to bottom. Socially Responsible Science Education recognizes the importance of all three Visions but has a particular leaning toward Vision III.



students could visit waterways near aquaculture sites, designing and carrying out their own student-led projects to understand the site's impacts before sharing these with local stakeholders. Here, the SSI is used to facilitate *socio-political action* (Hodson, 2011) (e.g., science for …) in which students contribute care for themselves, others, and the community as empathic advocates. Relating to how I conceptualize SRSE, throughout this vignette, each Vision built and supported the others. For example, the focus on critical literacy could then prompt students to think more deeply about additional conceptual literacy understandings (S.A. Scott, personal communication June 21, 2019). This will be further explored throughout the rest of this chapter.

2.2 Frameworks Supporting Socially Responsible Science Education

Due to the relative novelty of 3-VSL, few studies highlight how teachers directly understand and use it in practice (cf. Fuchs, 2023; Salinas et al., 2022). For this reason, established frameworks are introduced that can be subsumed under the three Visions and share the same thrust of SRSE: they (1) recognize the mutually supportive nature of the three Visions and (2) show evidence and potential of working towards Vision III outcomes. In this Chapter, these frameworks are used to establish teachers' perceptions of approaches that support Vision III, which, in turn, are used to inform the professional development intervention. Their compartmentalization here is primarily for analytic purposes despite their several connections and distinctions (Bencze et al., 2020). To reiterate, at this point, the three Visions are an organizing heuristic to think about the myriad goals of science education in terms of the term scientific literacy. SRSE is a movement towards Vision III while recognizing the importance of the other Visions. The frameworks reviewed give clues as to how teachers understand, implement, and can be supported with SRSE practices.

The frameworks reviewed include:

1. Science-Technology-Society-Environment education (STSE) (Pedretti & Nazir, 2011).
2. Socioscientific Issues-based education (Sadler, 2011; Zeidler, 2007).
3. Critical Pedagogy of Place (Gruenewald, 2003).
4. Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments (Bencze, 2017).

Other frameworks were considered (e.g., Socio-Scientific Inquiry-Based Learning [Levinson, 2018b] and Socially-Acute Questions [Simonneaux & Legardez, 2010]), however, the current list was deemed a manageable starting point for this review. The four frameworks chosen have diverse ontological, epistemological, axiological, and methodological orientations (see Bencze et al., 2020). However, that discussion is not in the scope of this chapter. Here, the aim is to show how authors indicate teachers approached the frameworks, including their potential for Vision III outcomes, and what challenges and opportunities arose as a result. The choice to synthesize teachers' perceptions of four frameworks was made in view of how the components an educator emphasizes are dependent on their own beliefs and ideas about science education, their students, the courses under consideration, and the school in which they work (Levinson, 2018a, 2018b). In this way, the review highlights the dialectical relationships between the tenets of each framework and the ways those tenets may manifest in practice. To summarize these relationships, Table 1 is provided. It highlights each framework's focus as well as design features and learning experiences teachers typically employ to achieve them. Design features are incorporated in the planning of learning experiences. Learning experiences are opportunities for learners to engage in different types of learning. Their presentation now is meant to foreground the upcoming discussion of teachers' perceptions of each framework. They give insights into classroom contexts, and the challenges and opportunities teachers might encounter.

Table 1

Summary of the STSE (socio-ecojustice current), Socioscientific Issue-based, Critical Pedagogy of Place and STEPWISE frameworks foci, design features, and learning experiences. Design features are incorporated in the planning of learning experiences. The numbers indicate which design feature and learning experience differences belong to which framework. The similarities and differences are across all frameworks, so do not take up each row in the table.

Framework and Focus	Design Features and Learning Experiences	
	Similarities	Differences
1. STSE socio-ecojustice • Critique and/or action on SSIs • Citizenship, civic responsibility, transformation, agency, emancipation	*Experiences should be designed to include*: compelling issues; reflexive thinking; stakeholder or networked analysis with respect to social, cultural, political, economic, moral, ethical, etc., considerations; primary or secondary research	*Experiences should be designed to include:* culminating projects[2,3,4]; apprenticeship-based and scaffolded learning[2,4]; personal and/or socio-political action[1,3,4]
2. Socioscientific Issue-based • Moral and ethical reasoning about SSIs • Virtue and character development, citizenship, civic responsibility	*Learners should have opportunities to engage with*: higher-order practices like analyzing, synthesizing, and evaluating information; negotiating social and ethical dimensions of an issue; interrogating personal beliefs and attitudes; engaging in informed decision-making and position-taking	*Learners should have opportunities to engage with:* nature of science perspectives and scientific ideas and theories[1,2,4]; inquiry-based learning[4]
3. Critical Pedagogy of Place • Pursuing actions that improve social and ecological life of local places • Citizenship, civic responsibility, transformation, agency, emancipation		
4. STEPWISE • Undertaking Research-informed and Negotiated Actions • Citizenship, civic responsibility, problem solving, transformation, agency, emancipation		

STSE has a long legacy (Gallagher, 1971; Gaskell, 1982; Solomon & Aikenhead, 1994) and is currently described as a set of educational approaches that emphasize connections among science, technology, society, and the environment. Organized into currents based on analyses of STSE education over 40 years, Pedretti and Nazir (2011) highlight how and why educators might focus on these connections, including foci on application and design, historical tenants of science, and value-centred outcomes. The socio-ecojustice current is of interest here, which advocates critique and action on SSIs through reflexive, critical, and place-based pedagogies (Pedretti & Nazir, 2011). Advocates of this perspective are found in science (Rip, 1978; Mueller & Zeidler, 2010) and environmental (Bowers, 2008; Hart et al., 1999) education and recognize that threatening issues related to diversity, equity, and the environment compel all school-based education to focus on developing skills and capacities for students to create a better world.

Despite the proponents, STSE has come under scrutiny over its 40-year history (e.g., Hodson, 2010; Steele, 2014; Zeidler et al., 2005). Zeidler et al. (2005) noted that while STSE education makes connections between various domains of STSE, it does not focus enough on students' moral-ethical and character development; components they argue are crucial for the critical examination of SSIs (Sadler, 2011). This practice itself can be seen as undemocratic if educators define for students what it means to be moral or ethical. However, Hodson (2014) extends this practice to include the critical examination of teachers' views with students. This aims to safeguard against initial moral and ethical definitions becoming dogma; rather, they are viewed as starting points. Zeidler et al. (2005) also argue that STSE education's goal is primarily to increase students' interest in science, rather than presenting a pedagogical strategy with defined goals. This critique, and the previous regarding moral-ethical reasoning, have been rebuffed themselves (e.g., Pedretti & Nazir, 2011); however, debate continues around STSE's scale, which some authors argue is too large to appreciate "the nuance of scientific, moral, personal, social, cultural, or political perspectives necessary to develop well-rounded citizens" (Zeilder & Newton, 2017, p. 58).

In contrast to STSE education, a Socioscientific Issues-based approach to science education aims to foster students' ability to morally and ethically reason about SSIs through dialogue, discussion and debate, while also developing students' virtue and character (Sadler, 2011; Zeidler & Nichols, 2009). This combination of development and abilities through personal decision-making on controversies leads students toward functional scientific literacy (Sadler & Zeidler, 2009; Zeidler, 2014). While not the prime focus, it can be coupled with other approaches (Burek & Zeidler, 2015; Mueller & Zeidler, 2010) to promote action on SSIs. Proponents of the Socioscientific Issues-based framework laud the centrality of scientific content knowledge, noting that knowledge for its own sake and "personal/aesthetic dimensions of science" (Hadzigeorgiou, 2015, p. 259) are not forgotten, as may be the case in other approaches seeking to develop Vision II or III of scientific literacy (Donnelly, 2004).

Distinguishing itself from STSE and Socioscientific Issues-based education is Critical Pedagogy of Place (Gruenewald, 2003). This pedagogy "encourages teachers and students to reinhabit their places … to pursue the kind of social action that improves the social and ecological life of places" (p. 7). Though not science-specific, Critical Pedagogy of Place can support Vision III by combining overt criticality and ideas that learning materials derived from the learner's context produce the best learning outcomes (Buxton, 2010; Smith, 2002; Sobel, 2004). Examples might include local park restoration projects (Schindel Dimick, 2016) and initiatives which study and clean up local watersheds (Zimmerman & Weible, 2017).

The blending of critical and place-based approaches draws critiques. If approached through inquiry-based learning alone, students' actions will likely be constrained by a lack of necessary knowledge and skills (Bencze & Alsop, 2009). Also salient is the idea that transformation always begets progress. Various communities have lived or still live with human and more-than-human entities in more beneficial ways than many 'modern' communities (S.A. Scott, personal communication, June 25, 2019). In this light, certain practices of conservation or renewal must also be considered (Bowers, 2008). Actively promoting 'transformation' also privileges a Western rights-based philosophy (Bowers, 2008). This can result in ideological conundrums for educators where emancipation and agency are advocated on one side, while the other insists adherence to a dominant framework is the only way to achieve it. Pedretti and Nazir (2011) note educators must take care in navigating "the fine line between indoctrination and empowerment" (p. 618) when working with students. Freedom to choose actions must be coupled with guidance on what actions might be most suitable, sustainable, and ethical.

Moving towards more prescriptive frameworks is STEPWISE (Bencze, 2017). This framework takes a strong apprenticeship orientation where teachers model skills, learners try them in supported environments and are then invited to test them on their own. STEPWISE is meant to produce Research-informed and Negotiated Actions (RiNA), where learners conduct their own primary and/or secondary research to inform and undertake actions which reduce harm from SSIs of interest. Some student RiNA projects include addressing paper waste from newspaper companies (Ramjewan et al., 2017), poster campaigns outlining connections between diet, transport, and climate change (Phillips-MacNeil et al., 2017), and school-wide awareness seminars on child labour (Hoeg et al., 2015).

STEPWISE draws on many strengths associated with the above-mentioned frameworks: action is explicitly promoted and modelled, science content knowledge is fostered, and special attention is given to the place and context of learning. However, new issues manifest as well. One is the strong apprenticeship model, which assumes teachers are needed to fill in gaps in student knowledge. This can be problematic given science teachers typically feel they lack knowledge pertaining to social issues and how to address them (Steele, 2013; Tidemand & Nielsen, 2017). However, Bencze (2017) notes that many teachers using STEPWISE felt more comfortable employing the approach when teacher-directed instruction was included. Aside from comfort, this makes practical sense since developing Vision III of scientific literacy must be complemented by developing the other visions. Scientific content knowledge and knowledge about the contexts in which science is situated are needed for decision-making and action (Hodson, 2014). It would be unwise and potentially harmful to assume all students can bring this knowledge from home (Bencze & Alsop, 2009).

STSE, Socioscientific Issued-based, Critical Pedagogy of Place, and STEPWISE can all support SRSE that aims to achieve Vision III of scientific literacy. Through varied currents, in combination, with other approaches, or as stand-alone frameworks, each, in turn, offers distinct benefits and caveats for science educators seeking to explore or undertake individual and societal actions and transformations in science class.

2.3 Teachers' Perceptions of the Frameworks

To review teachers' perceptions of each framework, I conducted a critical review (Eva, 2008; Fuchs et al., 2015; Grant & Booth, 2009; Kahlke et al., 2023)[3]. To organize the perceptions, I constructed categories which would be significant to the study's aims of designing teacher professional development and understanding the results of my research. The categories included (1) espoused benefits to students (Section 2.3.1), (2) teachers' concerns (Section 2.3.2), and (3) system level actants (Section 2.3.3). The 'espoused benefits to students' category relate to the benefits or detriments teachers' felt the frameworks posed for students learning science. The 'teacher concerns' category relates to factors the teachers felt they had control over (e.g., resource acquisition) and that influenced their implementation of the framework. The 'system level actants' category relates to living, non-living and symbolic elements beyond individual teachers' loci of classroom control, such as prescribed curriculum and colleagues' beliefs. What follows is a pooling and discussion of perceptions along the three categories mentioned. Section 2.3.4 draws lessons from the rest of Section 2.3 to forward implications for teacher professional development, justifying the approach of Learning study.

2.3.1 Espoused Benefits to Student

Teachers typically agree that each framework benefits student learning in line with Vision I and II outcomes. Through interviewing 22 secondary science teachers, Sadler et al. (2006) found that participants placed Socioscientific Issues-based benefits in two categories. The first argues that students entering a modern democratic society need knowledge of and about

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[3] See Fuchs and Tan (2022) for more details on the method of review. Most literature in Critical Pedagogy of Place appears to be focused on student outcomes (e.g., Leonard et al., 2016). I was able to locate only one study that reported on teachers' perceptions related to Critical Pedagogy of Place perspectives in secondary science (Zimmerman & Weible, 2017). As such, the review was expanded to include secondary science teachers' perceptions of Place-Based Pedagogy in addition to Critical Pedagogy of Place.

science to make informed choices on complex issues. Thus, Socioscientific Issues-based instruction is seen as a method to prepare students for life beyond school (i.e., a Vision II orientation). The second category posits that Socioscientific Issues-based approaches add relevance, applicability, and engagement to typical science content presented in class, strengthening students' Vision I understandings. These categories are echoed in studies reporting on the benefits to students of the other frameworks.

Mansour (2010) and Steele (2013) found that teachers employing STSE wanted students to practice science in meaningful contexts and feel prepared to make informed choices on science-related topics now and in the future. This was similar for STEPWISE, Place-Based Pedagogy, and Critical Pedagogy of Place (Bencze, 2017; Smith & Sobel, 2014; Zimmerman & Weible, 2017). However, for some teachers, the frameworks were chosen because of their ability to foster Vision III outcomes, like acting on SSIs. In Zimmerman and Weible's (2017) study, which focused on secondary science students studying and cleaning a local watershed, they comment on the teachers' intentions:

> Through explicitly articulating the connections between the man-made structures surrounding the local watershed and environmental issues, the teachers intended for the students to develop an action-oriented mindset focused on the local watershed and their community (p. 15).

Interestingly, this outcome of promoting 'action' appears to be divided among teachers. Some pursue the frameworks to develop students' sense of advocacy or activism (entailing an explicit political dimension), and others to develop students' action-oriented mindsets (aims at apolitical) (Bencze, 2017; Pedretti & Bellomo, 2013; Zimmerman & Weible, 2017). Both sets of teachers favoured the frameworks because they encouraged some form of 'doing' (i.e., "engage in action rather than just talk about it" [Hodson, 2014, p. 69]), however, the former group was more attuned to explicit politicized science education of Vision III, including themes of emancipation and transforming one's personal conditions, and actions like letter writing to local politicians or lobbying powerbrokers. The latter group was more interested in trying to avoid politics altogether, favouring school-based projects that raised awareness of SSIs, but which could nonetheless be interpreted as apolitical when acted upon due to their context's social zeitgeist. Actions of this nature in Canada might include recycling campaigns or garden planting.

Despite these actions being interpreted as apolitical, they have political dimensions (i.e., supporting the dominant ideology [Gardner Burt, 2016; Lundmark, 2003; Ruitenberg, 2009]). What appears to delineate the groups is the *awareness* of the political nature and actions that follow. Teachers from Pedretti and Bellomo (2013) indicated on the one hand, "It is great to feel that my passion for environmental and social justice can be relevant within a science curriculum that is [typically] focused on content, objectivity and political neutrality," further noting, "I am now more confident about sharing and empowering my students in a role of advocacy" (p. 425). On the other hand, "getting students involved was important," but "I have very strong personal environmental and political viewpoints, [and] I tend to keep that out of my classroom" (Pedretti & Bellomo, 2013, p. 427). When action was defined politically, some teachers felt it would be too challenging for their pupils, citing developmental readiness and other priorities (e.g., exams) as key reasons (Pedretti & Bellomo, 2013).

Supporting Vision I outcomes, Tidemand and Nielson (2017) found that half of their sample of 209 secondary biology teachers characterized Socioscientific Issues-based instruction as important to frame the biological content in the curriculum, enhancing its relevance and applicability. Similar results were reported in Critical Pedagogy of Place (Zimmerman & Weible, 2017), STSE (Pedretti & Bellomo, 2013), and STEPWISE approaches (Bencze, 2017; Krstovic, 2017), highlighting the importance teachers' place on supporting Vision I outcomes.

Overall, very few teachers commented that the frameworks provided no benefits for students (cf. Sadler et al., 2006). Rather, benefits were disproportionately expressed in line with Vision II over Vision III. In other words, teachers were ready to engage students in discussions of how science is related to society but were more hesitant to extend these dialogues toward propelling action, and even more hesitant to extend these dialogues to propelling sociopolitical action. On a larger scale, the focus on Vision II-oriented benefits echoes Cross and Price's (1996) framing of competing perspectives in science education:

> Until a critical mass of science teachers' ideology of teaching changes, committed science teachers and teacher educators will face an uphill battle against dominant traditional practices… The extent to which teachers may be reconceptualizing the nature of their task is an important indicator of possible progress toward a breakdown of the traditional value-free notion of teaching science. (p. 320)

Twenty-five years later, this statement holds weight. Although a 'critical mass' has likely not been met, the studies reviewed indicate some teachers are 'reconceptualizing' their practice, noting the pedagogical and social utilities of doing so (Pedretti & Bellomo, 2013; Lee & Witz, 2009; Mansour, 2010; Steele, 2013). While reconceptualization seems more in line with Vision II than Vision III, this result reflects a minimal gaining of momentum in the 'uphill battle' (Cross & Price, 1996).

On a smaller scale, the focus on Vision II-oriented benefits is sensible. Heavily Vision III-oriented curricula ask a lot of science teachers (Hodson, 2013). Having students research SSIs thoroughly, propose action based on the results, engage in action meaningfully, and reflect on action in hopes of doing it better in the future is a considerable commitment. The signature pedagogies (Shulman, 2005) of most science teachers' past science experiences likely run counter to the open-ended, subjective, political, and uncertain nature of the list just described (Aikenhead, 2006; Pedretti & Nazir, 2015). Add to that the relative newness of explicit Vision III-oriented curricula (Blades, 2019; Onwu, 2017) and familiarity with new science education orientations may be as important as conviction when describing Vision II over Vision III benefits. Indeed, teachers already familiar with Vision III orientations (e.g., through the STSE socio-ecojustice current) commented on the frameworks' potential to foster engaged citizens, problem solvers, and individuals who would be aware of and engage in action for what they thought was right (Krstovic, 2017; Pedretti & Bellomo, 2013; Ramjewan et al., 2017).

Benefits to students in line with Vision III outcomes differed by how teachers defined "individual and societal actions and transformations" (Sjöström et al., 2017, p. 182). These definitions were largely based on teachers' own beliefs and ideas about science education (Pedretti & Bellomo, 2013; Pedretti, 1997). Specifically, a perceived political orientation to action was an area of contention while general action, perceived as apolitical, was more welcoming. Despite few teachers expressing student benefits in terms of political action, this initial foray into Vision III could be nonetheless desirable as it highlights the diversity of goals *inside* each Vision. These alternative goals may be important to facilitate movement towards political action orientations. For example, the 'critical' in critical scientific literacy includes "both an awareness and critical stance" (Sjöström et al., 2017, p. 182) toward risks associated with the products of science and technology. This recognizes one's need to be aware of harm before one can address it. Critical scientific literacy then builds off this recognition, introducing individual and/or societal actions which, depending on how the actions are positioned (Levinson, 2010), can lead to individual and/or societal transformations. The opposite could also be true, where individual transformations (e.g., a new way of thinking about problems) can lead to individual actions, and, depending on how those actions are positioned, societal transformations and/or actions could follow. Regardless, focusing on awareness of harms from certain SSIs and sharing them, or engaging in perceived apolitical action to reduce those harms (e.g., as shared above, gardening or recycling in most Canadian school contexts), is certainly in line with SRSE and the main thrust of critical scientific literacy. Even if harm awareness or reduction is initially seen as apolitical, the practice could nonetheless lead teachers one step further, after each engagement, to the more political nature of Vision III (e.g., Hoeg et al., 2017; Krstovic, 2017).

Teachers' perceptions across the frameworks show their potential in supporting Vision I, II, and III outcomes. Preferences were skewed toward Vision I and II and split by the recognition of a politicized or apolitical action-oriented Vision III. In other words, teachers were ready to infuse their science curricula with the frameworks mentioned to add relevance and applicably and engage students in discussions of how science relates to society. They were more hesitant to extend these dialogues toward propelling general action, and even more hesitant to extend these dialogues to propelling sociopolitical action. However, instructional change is slow (Kennedy, 2016), and the relative newness (e.g., Allchin, 2021) and/or difficulties (Hodson, 2013) of Vision III orientations foreshadow patience and continued exploration. Indeed, successive, gradual movement into new practice areas may yet open possibilities for continued investigation and adoption (Krstovic, 2017).

2.3.2 Teachers' Concerns

For teachers employing the frameworks, many relished the opportunities they provided to explore new knowledge domains, like general pedagogical practices or issue-specific content areas (Gray & Bryce, 2006). The frameworks were also seen as stepping-off points for professional development (Pedretti & Bellomo, 2013), to learn new skills (e.g., how to facilitate students' value reflections), or to resolve tensions identified in classrooms (e.g., how to support students as human beings *and* science learners) (Lee & Witz, 2009). However, based on the studies reviewed, this appeared to be a minority of teachers. Others viewed the frameworks as an impediment due to the time that a thorough exploration of issues or new pedagogies would take (Pedretti & Bellomo, 2013; Sadler et al., 2006). A paucity of resources relating to curriculum materials, pedagogical guidance, assessment approaches, and issue-specific/specialized knowledge prevented many teachers from considering the frameworks (Mansour, 2010; Meichtry & Smith, 2007; Sadler et al., 2006) or barred further exploration (Bencze, 2017; Can et al., 2017; Zimmerman & Wieble, 2017).

Lack of resources, as listed above, was a concern for teachers considering the frameworks and those already using them. However, these concerns came despite many resources existing (e.g., www.stepwiser.ca) or being made available by the study authors. In this sense, it appears the type or framing of resources, and the time required to find, use, and/or revise them to specific contexts, was a deterrent for framework implementation.

For example, in a professional development program labelled 'summer school', teachers were provided with social, moral, and science-related resources concerning the SSI of biotechnology (Gray & Bryce, 2006). Science-related resources included expert presentations on developments in biotechnology (e.g., advances in genome sequencing and connections to the Human Genome Project), while social and moral resources included presentations on the ethical and legal issues associated with those developments (e.g., genetic counselling, genetic discrimination). However, participants still wanted those presentations to be enriched with pedagogical considerations (i.e., framing of resource) – desiring resources on 'how' to teach something contra 'what' to teach, like facilitating a morally grounded discussion around the sharing of genetic information. Teachers also wanted more reflective time and direction to place pedagogical considerations in their classrooms. One participant noted:

> There was nothing really at that summer school which provided guidance on how to approach day-to-day teaching … an excellent experience to give in-depth background that you can add to what you have to teach the children … [but] wasn't so good when it came to giving advice on how to actually handle the delivery of the course itself (Gray & Bryce, 2006, p. 184).

These multitudes of considerations resulted in a 'back to basics' sentiment for many teachers, where non-traditional approaches like discussions, debates, and case studies would be considered, but only as time permitted (Bencze, 2017; Pedretti & Bellomo, 2013).

In Zimmerman and Wieble's (2017) study, unfamiliarity with the community meant that when teachers tried to encourage a critical component to the place-based framework, they were hard-pressed to find a starting point for sociopolitical action. This precipitated students' action potential (Huffling et al., 2017). The students were able to propose individual actions (e.g., don't litter, use the recycling bin, pick up garbage that was not your own [Zimmerman & Wieble, 2017, p. 23]), but collective actions at community levels (e.g., organizing a watershed cleanup, p. 27) did not materialize.

Finally, a small number of teachers questioned if the frameworks belonged in science education at all (Bencze, 2017; Sadler et al., 2006; Tidemand & Nielson, 2017). Some teachers from Tidemand and Nielson's (2017) study preferred biological content to societal issues, with one teacher calling Socioscientific Issues-based learning "boring" (p. 54). The authors speculated this was due to personal beliefs and interests. Moreover, Sadler et al. (2006) reported one participant rejected the notion that ethics or values had a place in science class at all: “I don’t think values play any role in science … and I don’t think we should have any sort of outside influence other than what’s going on in the science world” (p. 366).

Comparing espoused benefits (Section 2.3.1) to teachers’ concerns, the benefits described were more easily theorized than achieved. SRSE is new ground, and it is one thing to imagine the framework's benefits to students and quite another to enact them in classroom contexts. The review showed that teachers’ beliefs about the purposes and goals of school science impacted degrees to which practical concerns were overcome. As implied through their beliefs, this delineation of teacher resistance may highlight ways science educators can be supported in pursuing SRSE.

As an example, for those teachers that felt the frameworks could support goals of science education they deemed important, practical concerns like lack of materials or self-assessed knowledge were deemed surmountable; what was required was a targeted focus on exploring the frameworks (Can et al., 2017; Pedretti & Bellomo, 2013). There were also groups of teachers just beginning to consider the frameworks, stressing many of the same practical concerns. However, for them, the concerns were deemed insurmountable (Pedretti & Bellomo, 2013; Sadler et al., 2006), requiring too much time to make substantial progress (Can et al., 2017; Bencze, 2017; Gray & Bryce, 2006). Finally, some teachers claimed the frameworks provided little use in their teaching. Practical concerns were too much to contend with, and/or the frameworks had no use from their perspective (Bencze, 2017; Sadler et al., 2006; Tidemand & Nielson, 2017). The literature has explored these teachers' perspectives extensively (e.g., Aikenhead, 1994, 2006).

All the groups above underscore what potential interventions and support systems might entail. For example, teachers that saw the utility of frameworks supporting SRSE overcame most practical concerns discussed (e.g., lack of resources). It follows that changing beliefs towards the frameworks and SRSE should be a primary focus if the goal is to support reform efforts. Teachers' beliefs are often considered the most important determinant of teacher practice (Fenstermacher, 1979; Pajares, 1992). Thus, this recommendation should not come as a surprise – notwithstanding the recognition that beliefs do not necessarily translate into equivalent practice because of, amongst other factors, collegial opposition (Bencze et al., 2006; Can et al., 2017).

That said, focusing on practical concerns deserves attention as well. Lack of resources, materials, and knowledge regarding issue-specific scientific/social topics are real concerns which barred those teachers from beginning to explore the frameworks towards full implementation. Importantly, these practical concerns may also impact those teachers still on the ideological fence regarding the frameworks. This comes from a general review of teacher professional development literature, which argues that a change in teacher practices, regardless of belief, can lead to a change in student outcomes: should the modified practice produce favourable outcomes, teachers' beliefs are likely to change as well (Clarke & Hollingsworth, 2002; Granger et al., 2019). Pascale et al. (2010) sum up this idea nicely by noting, "It's easier to act your way into a new way of thinking, than to think your way into a new way of acting" (p. 38). Applied to this context, a focus on practical concerns has the potential to benefit not only teachers' who note utility in the frameworks but lack the capacity to do so but also teachers who are sitting on the ideological fence.

In this section, teachers' concerns with framework implementation centred on a paucity of resources related to framework-specific content (e.g., issue-specific/specialized knowledge), pedagogical practices (e.g., general teaching practices supporting framework implementation), and pedagogical content knowledge and how they were framed. Teachers wanted to place these knowledge domains (e.g., curriculum materials, assessment approaches, community familiarity, etc.) in their classroom contexts (e.g., Cochran et al., 1993) to concretize their development. Teachers that saw benefits in the frameworks frequently overcame the barriers listed above; however, this was a precarious balance – benefits were often easier theorized than achieved. This points to the requirement of *in situ* support and knowledge area exploration to fully support teachers.

2.3.3 System Level Actants

System level actants can be viewed as networks of living, non-living and symbolic elements supporting particular goals. Bencze (2020), drawing from Actor-Network-Theory [Latour, 2005] and Foucault's [2008] work in this area, might call these 'dispositifs.' These networks of mostly cooperating actants may work as mechanisms in the pursuit of certain outcomes. For example, mandated curricula, professional development policies, school-specific ideologies, and broader global educational movements which focus on teacher quality (Fuchs et al., 2022; Sahlberg, 2011) work to enhance or diminish certain educative practices (Bencze, 2020). Authors argue that government tendencies, often influenced by private sector interests, have, over several years, reduced resources and time for teacher professional development (Mockler, 2013; Roseler & Dentzau, 2013). This assemblage of government and private sector interests can therefore be seen to work in a network influencing teaching practice. Alternatively, one can imagine different networks of actants which might be aligned into new dispositifs that counter declining resources for teacher professional development (e.g., teachers' unions, student advocacy groups). In the context of this study, the dispositif concept is useful to foreground the makeup of actants and the potential 'glue' between them (Bencze, 2020) that can be leveraged to support greater diversity in science education goals.

Based on the review, teachers cited specific actants outside their loci of control as part of dispositifs which influenced framework implementation. The main actant is the prescribed curriculum. Expected coverage of curricular content (Gray & Bryce, 2006; Bencze, 2017; Steele, 2013), mandatory lab time (Tidemand & Nielson, 2017), and end-of-year exams or standardized tests (Pedretti & Bellomo, 2013; Sadler et al., 2006) all came up as crucial determinants of why, when, how, and how often the approaches were employed. Curricular content that would support or fulfill these other priorities, when weighed against administrative duties of implementing non-traditional approaches well (e.g., approaches requiring permission slips for field trips), meant teachers had to carefully consider where their time would best be allocated (Can et al., 2017; Smith & Sobel, 2014).

That said, sometimes the curriculum itself was an invitation to the approaches. One of six secondary teachers from Bencze's (2017) study on teachers using STEPWISE had students engage in sociopolitical action numerous times throughout many semesters (Krstovic, 2017). They noted that prioritization of STSE issues in the curriculum drove them to take STEPWISE seriously (Bencze & Krstovic, 2017). However, this came with a caveat: while they felt supported to engage in science education for individual and societal actions by some curriculum features, they felt constrained by others. Whereas STSE was prioritized in the official science curriculum, appearing first among three overarching goals for science education (Ontario MoE, 2008, p. 15), the assessment portion of the document placed STSE issues last (Ontario MoE, 2008, p. 27). For the participant, these conflicting messages resulted in their inability to engage in crucial aspects of STEPWISE, like having students fully design and conduct student-led open-ended research, as other assessment priorities had to be met.

Other notable system level actants included co-workers and administrative support (Mansour, 2010). One teacher in the Can et al.'s (2017) study commented on their colleague's reaction to discussing their use of birdwatching as a place-based approach to science education in the staff room. Sadly, "all the other [teachers] laughed loudly" (p. 741) when this was brought up and continued to make jokes about the activity throughout the year. As found in pre-service STSE studies, school community and school-specific ideologies play an important role when teachers consider non-traditional approaches to science instruction (Pedretti et al., 2008; MacLeod, 2014).

The curriculum was the most mentioned system level actant. As a barrier, teachers overwhelmingly viewed the frameworks as taking the time they needed to cover 'the content' or the conceptual and skill-based knowledge of 'typical' science curricula. The content's importance was justified based on required examinations (Can et al., 2017; Gray & Bryce, 2006; Sadler et al., 2006), course progression and scaffolding (Tidemand & Nielson, 2017), or by the fact that it was simply in the curriculum (Bencze, 2017; Pedretti & Bellomo, 2013). For this latter influence, a concerted effort is needed to advocate for more skills, competencies, and values in the formal science curriculum. For the former, the empirical evidence, as previously highlighted, shows that frameworks supporting SRSE do not detract from traditional science education goals (e.g., learning or doing science [Hodson, 2011]). Educators need to be supported in dispelling the false dichotomy of "teaching to promote socio-scientific decision making and teaching for conceptual understanding" (Sadler et al., 2006, p. 373). Both can be achieved together in what might be seen as 'pedagogical synchronicity.'

As an invitation, the explicit curricular citation of frameworks which support SRSE invited some teachers to engage in non-traditional practices (Bencze, 2017; Tidemand & Nielson, 2017). This top-down approach underscores the importance of curricular documents in supporting new practices. However, curricular inconsistency between specific competencies (e.g., students engaging in open-ended inquiry) and assessment mandates that favour factual mastery barred many interested teachers from fully using the frameworks (Tidemand & Nielson, 2017).

2.3.4 Implications for Supporting SRSE Practice

The teachers' concerns and beliefs around the employment of frameworks congruent with SRSE highlight areas that need to be attended to for different visions of scientific literacy to be fulfilled within current school settings. These areas include the prescribed curriculum many teachers rely on for their teaching, the necessary support in terms of teacher professional development opportunities, and the hesitancy, spurred by beliefs, familiarity, or other factors, to engage with the diversity of Vision III practices. All can be viewed as potential actants which can be aligned to promote SRSE.

The curriculum is a powerful influencer for teachers' employment of frameworks which support SRSE. To work towards Vision III, more skills, competencies, and values are needed in the formal science curriculum and the assessment mandates that support them. If the curriculum carries goals related to Vision III of scientific literacy while at the same time precluding them through assessment approaches, teachers, regardless of intent, will be unable to fully reach their goals. As already shown in the introduction, the revised BC curriculum has approaches which support Vision III of scientific literacy fully integrated into its policy documents. Being conducted in BC, this study, therefore, represents an important opportunity to understand how teachers approach supportive curriculum in Vision III contexts.

Key features of professional development which directly tie to teachers' concerns outlined above include a focus on teachers' own context and practice, collaboration, and sustained, well supported professional development opportunities. Professional development focusing on teachers' own context and practice addresses a lack of resource concerns while promoting an increase in understanding about implementation methods. Participants in Gray and Bryce's (2006) study were given ample resources to address concerns regarding the use of the Socioscientific Issue-based framework. However, they still wanted to place those resources in their own practice to feel comfortable with implementation. This speaks to Royce's (2010) assertion that "what we know to be true for students also apply in this [professional development] situation to adults. Teachers learn best by doing and building their own understandings rather than being told" (p. 6). In other words, learning principles often applied to pedagogy should equally apply to andragogy. Teachers should be invited to explore and iterate on SRSE in practice to expand their understandings and see for themselves how they can best be adapted to their context.

Teachers investigating their practice may also work to test pedagogical and assessment approaches, which, once tested and then shared, can alleviate some concerns teachers associate with a lack of resources (Mansour, 2010; Sadler et al., 2006). Such practice-focused teacher professional development is numerous and includes various models of collaborative action research (Bencze & Hodson, 1999; Fazio, 2009; Somekh & Zeichner, 2009) or teacher inquiry (Clarke & Erickson, 2003), as well as more specific action research variants such as Lesson study or Learning study (Ko, 2019a).

In most of these professional development models, teacher collaboration is prioritized. This facilitates the recursive convergence of ideas and beliefs, which, when focused on practice, strengthens the building and testing of resources in real classroom settings (Fuchs et al., 2021). Importantly, sharing more general beliefs about science education gives "teachers a chance to bring up, discuss, and perhaps reconcile competing goals or visions of education" (Lewis & Tsuchida, 1998, p. 16). This point is salient for SRSE because of its departure from traditional science education. The explicit articulation, examination, and critique of science education beliefs should be encouraged. It may show teachers how their aims of science education can be supported and expanded by SRSE (Gray & Bryce, 2006; Pedretti & Bellomo, 2013). In this light, teachers' beliefs are viewed as invitations to the frameworks and novel approaches rather than barriers (Lee & Witz, 2009). Collaboration can also foster conducive norms of a burgeoning professional community (Lewis et al., 2009), where teachers are invited to see themselves as scholars, capable of dealing with curriculum reform systematically and creatively (Tan & Nashon, 2015; Zhang et al., 2023). These norms may also alleviate teachers' concerns about judgemental school communities (Can et al., 2017).

When engaging with SRSE, science teachers must navigate many considerations. When addressing these through collaborative and practice-focused means, it is no surprise that sustained, well-supported development should be pursued that moves away from limited-impact one-off formats (Elmore, 2002). Generally, these collaborative spaces could be complemented by a knowledgeable other (e.g., Bencze, 2017), who shares expertise around the frameworks and facilitates meetings. This could come from a teacher in the school, perhaps who has recently engaged in an out-of-school professional development series and is keen to share with their colleagues. Alternatively, partnerships between schools and/or departments and science education researchers and/or teacher-educators from tertiary institutions could be made. Both examples support professional development sustainability (Guskey, 2002).

Teachers' espoused benefits to students showed a leaning towards Vision II, some engagement in Vision III, and limited engagement with the political nature of Vision III. Given this study's focus on Vision III aspects of 3-VSL, and the understandable difficulty teachers' have in moving practice in that direction, theoretical knowledge can be leveraged to support teachers. It can "systematically structure a teacher's understanding of his or her work in a particular context" (Stenhouse, 1975, p. 157). Indeed, teachers' use of theoretical concepts to ground understanding and push past familiar areas of knowledge, skill, and experience are rising strategies in contemporary education literature (Elliott, 2012, 2015; Lewis et al., 2019; Pang & Marton, 2003; Runesson, 2016; Tan et al., 2019).

2.3.5 Summary

The totality of Section 2.3 points to intervention strategies. They should include a focus on teachers' context and practice, being sustained over a period that allows for deep exploration, while in collaboration with other educators or knowledgeable others, and supported by rich theoretical perspectives. A professional development approach capturing all recommendations is the Learning study. It is implemented in this dissertation to both study and support teachers' exploration of SRSE. Since the Learning study constitutes part of my methods, its origins, features, and use in science education contexts is presented in the methodology chapter, Chapter 3. There, I also describe how I adapted the Learning study for this work.

2.4 Theoretical Framework

I draw on one theoretical framework for two purposes in this dissertation. First, the 3-VSL is used as a framework to structure how the participants in this study understood and enacted SRSE. In this instance, I draw on the 3-VSL to complement the phenomenographic perspectives I borrow to understand teacher learning. Second, the 3-VSL frames the Learning study discourse itself, acting as a lens (Tan, 2014a) by which the participants in this study plan, enact, and evaluate their teaching and learning experiences in the Learning study.

The 3-VSL was introduced in Section 2.1. As a reminder, it contains conceptual literacy (Vision I), which is aimed at science's internal processes and products. Contextual literacy (Vision II) focuses on the relationships and impacts science has on society, and critical literacy (Vision III) targets “science for individual and societal actions and transformations” (Sjöström et al., 2017, p. 182) (see also Valladares [2021]). The first two Visions of Sjöström et al.’s (2017) heuristic can be attributed to Robert’s (2007, 2011), though all three Visions’ aims have long histories in science education literature (e.g., Bernal, 1949; Layton, 1972; Shen, 1975). The 3-VSL has been employed in other studies to organize teacher professional development (Harding & Fuchs, 2021), design instructional sequences (Fuchs, 2023; Nida et al., 2021), orient broad competencies, such as socioscientific reasoning skills (Romine et al., 2020), conceptualize new goals and roles for science museums (Pedretti & Iannini, 2020), and frame critical discourse analysis (Guerrero & Torres-Olave, 2022), among several other roles (e.g., Sjöström et al., 2016; Sjöström & Eilks, 2018). The dual use of 3-VSL in this study is compatible and consistent with the study’s overarching goals.

In relation to this dissertation, I am drawn to 3-VSL for its explicit focus on Vision III while maintaining the importance of the other Visions. In my view, this allows for nuanced examinations of SRSE understanding, practices, and challenges from the viewpoint of a researcher as well as a teacher. It also allows for a particular focus on Vision III-oriented ideas. As highlighted above, the critical literacy Vision is not a panacea to science education difficulties. However, it *is* a Vision most science teachers are unfamiliar with and one which science teachers have specific difficulty enacting (Section 2.3). Moreover, it encompasses some of the most worthwhile goals in responding to our world's perils (e.g., Bencze, 2020; Hodson, 2011; Levisnon 2018a;). It, therefore, deserves attention.

The use of the 3-VSL to frame my study and the Learning study discourse drew from the same two theoretical perspectives. These are presented in Table 2. The first is that the 3-VSL is a continuum of scientific literacy representing different curricular emphases. The second is that there is a plurality of goals within Vision III. Since each perspective is employed in slightly different ways in this dissertation (i.e., from the view of the researcher and the view of the Learning study participants, or teachers), each perspective will be discussed, followed by how it will be used.

2.4.1 Three Visions of Scientific Literacy: A Continuum of Engagement

The first element of the 3-VSL I draw on to frame the study and the Learning study discourse comes from its continuous nature. The Vision's nuanced connections and distinctions provide the first theoretical perspective to approach SRSE. The three Visions "have the learning of and about science in common, but they accentuate different curriculum emphases" (Sjöström et al., 2017, p. 182).

Table 2

Summary of theoretical perspectives used to frame the study and the Learning study discourse. Adapted from Tan et al. (2019b.)

	Three Visions of Scientific Literacy as a continuum	Plurality of Vision III Goals
Focus	Each Vision represents a continuum of scientific literacy with different curricular emphases (Sjöström et al., 2017).	Vision III encompasses science for individual and societal actions and transformations (Sjöström et al., 2017).
Key Idea	The Visions are connected and mutually supportive. Scientific content knowledge and knowledge about the contexts in which science is situated are needed for decision-making and action (Hodson, 2014).	Vision III includes both an awareness and critical stance toward relevant SSIs. Multiple goals for Vision III are possible (Bencze, 2017; Gruenewald, 2003; Pedretti & Nazir, 2011; Hodson, 2011; Sadler, 2011).
Relationship with teaching instruction	As the focus moves from Vision I to III, there is an increasing emphasis on general educational skill development or 'education through science.' Vision III to I shows an increasing emphasis on traditional science content learning or 'science through education' (Sjöström et al., 2017).	Students should proceed to whichever critical goals are appropriate to the topic and their own learning/emotional level.

For example, an increasing emphasis on Vision III tends to represent an increasing emphasis on general educational skill development or a focus on 'education through science' (Sjöström et al., 2017). Critical disposition-taking and multistakeholder analysis are common in Vision III engagements (Bencze, 2017). These are more general skills applicable across a range of disciplines. In Vision III, they are often aimed at critical sustainability outcomes (Valladares, 2021). By contrast, an emphasis on Vision I represents an increasing emphasis on traditional science content learning or a focus on 'science through education' (Sjöström et al., 2017). In these instances, learning science and doing science dominate. In Vision I, these practices are often aimed at developing scientific understanding (Sjöström & Eilks, 2018; Valladares, 2021).

This gradient of ‘education through science’ and ‘science through education’ is an example of how I will use the 3-VSL to interpret and analyze the teachers’ SRSE understanding and how that understanding is put into practice.

Conceptualizing SRSE as part of a continuum, as the three Visions do, gives primacy to the Visions’ connections rather than only highlighting their distinctions. This allows for a more nuanced examination of SRSE possibilities. Taking the SSI of aquaculture from Section 2.1.1 to illustrate, the mechanisms which make aquaculture potentially harmful, and the knowledge of what can be done to reduce that harm, contain related elements of conceptual, contextual, and critical literacy understanding. For example, how high nitrogen levels accumulate around aquaculture sites (Vision I, conceptual literacy), how those levels might impact other aquatic species, recreational fishing, and the aquaculture industry (Vision II, contextual literacy), and how both sets of information might be leveraged to lobby powerbrokers, gain new empathetic perspectives, or raise awareness (Vision III, critical literacy), are connected ideas (e.g., Liu, 2013; Valladares, 2021). To frame the Learning study, I will make it clear that in the context of SRSE, the Visions are necessarily connected and mutually supportive: scientific content knowledge (Vision I) and knowledge about the contexts in which science is situated (Vision II) are needed for decision-making and action (Vision III).

Based on this framing, the continuum and connections between the different Visions allow science educators to consider more far-reaching aspects of science education. Particularly, this framing allows for aspects of scientific literacy science teachers are most likely familiar with, such as those represented by conceptual or contextual literacy, to be considered and expanded to more diverse areas (e.g., critical literacy). This more inclusive view of what the teachers perceive as scientific literacy and their own perceptions of the purposes of science education allows for these connections to be proposed, explored, and analyzed within the discourse of the Learning study.

2.4.2 Three Visions of Scientific Literacy: Plurality of Vision III Goals

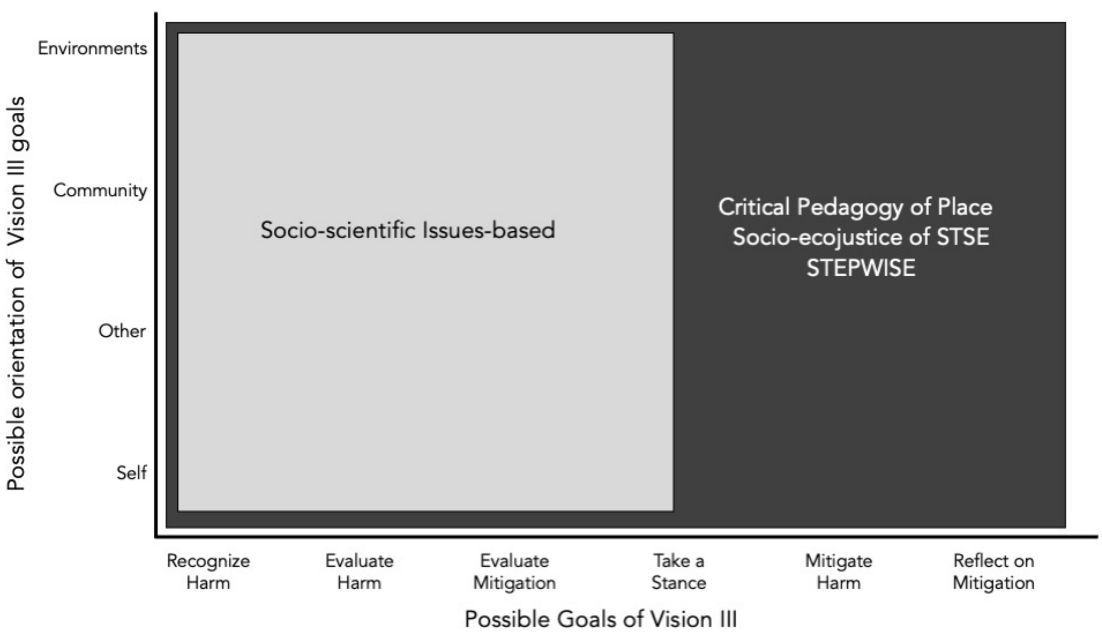
The second element of the 3-VSL I draw on to frame the study and the Learning study discourse comes from the explicit focus on Vision III. Simply, having its own category enables Vision III to be a goal, if so desired, in and of itself, rather than treated as an add-on (Hodson, 2003). The additional category of Vision III is crucial because promoting social responsibility with students is often argued to be achievable only with practice (Hodson, 2011). Though that practice can vary considerably (e.g., planting for a community garden or organizing a school 'energy day' [Levinson, 2018b]), the stakes are too high to place it as another Vision II formulation (Bencze, 2020).

In view of how Vision I and Vision II are not mutually excluded from Vision III, I borrow from the plurality of potential Vision III goals (e.g., Bencze, 2017; Gruenewald, 2003; Pedretti & Nazir, 2011; Hodson, 2011; Sadler, 2011; Sjöström et al., 2017; Valladares, 2021), as discussed in Section 2.3.1., to further develop my use of the 3-VSL in this work. Specifically, I developed a conceptual tool to visualize possible Vision III goals to frame my and the Learning study participants' SRSE understandings. The tool was constructed by drawing upon the four science education frameworks already highlighted above (i.e., Critical Pedagogy of Place, Socioscientific Issues-base, STEPWISE, STSE socio-ecojustice current), Hodson's (2011) 'steps' for socio-political action, and the revised BC science curriculum (BCME, 2018a, 2018b, 2018c). This tool is presented in Figure 3.

Figure 3 highlights possible ways to engage with SSI *within* Vision III. The horizontal axis is a simplified version of Hodson's (2011) eight steps for achieving socio-political action in science learning contexts through SSI engagement (p. xi). The vertical axis details the possible orientation of those goals following the revised BC science curriculum.

Figure 3

Conceptual tool visualizing possible Vision III goals. The horizontal axis is a modified version of Hodson's (2011) eight steps for achieving socio-political action in science learning contexts. The vertical axis highlights the possible orientation of those goals adapted from the revised British Columbia Science Curriculum (BCME, 2018a, 2018b, 2018c). The lack of arrows on each axis is intentional. Figure 3 is conceptual, not directive. Four science education frameworks are placed to further contextualize possible SRSE framings.



These include self, others, community, and environments (BCME, 2018a. 2018b, 2018c). Notably, the lack of arrows on each axis is intentional. There are meant to be no correct 'outcomes' implied by Figure 3; it is a tool to think about Vision III enactments.

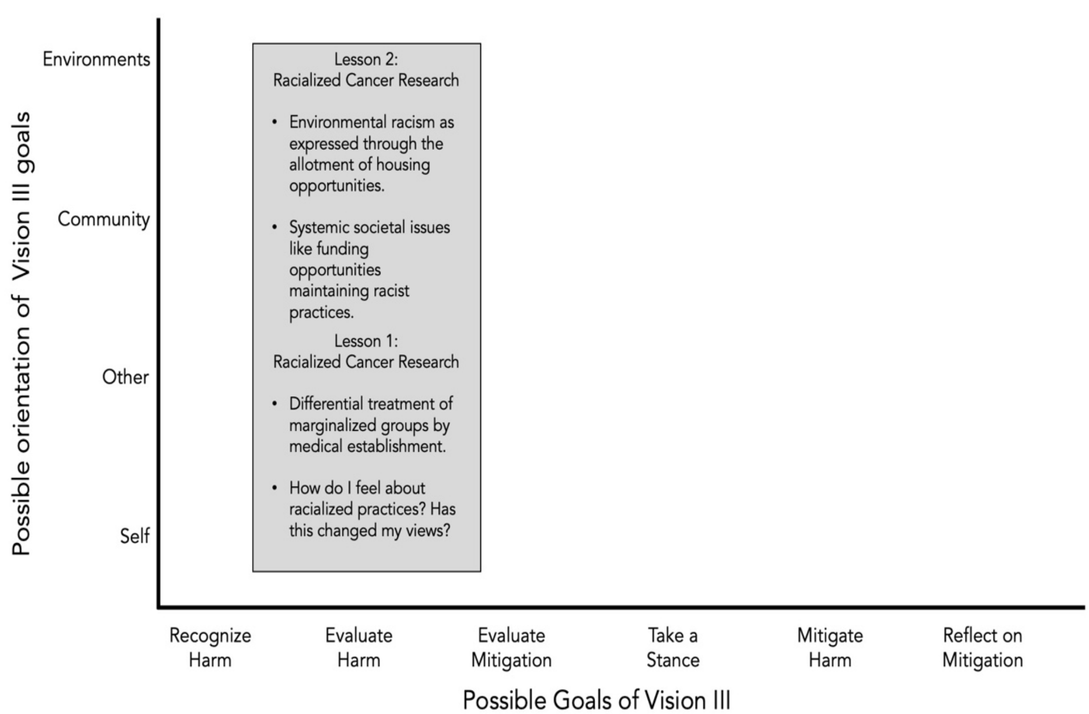
For the framing of this study overall (i.e., at the level of the researcher), the four science education frameworks reviewed in this chapter (Section 2.2) were placed in Figure 3. This was done to aid my interpretation of the teachers' potential understanding and enactments of SRSE. They could be 'plotted' using the axes from Figure 3 (which will be shown in Chapter 5, Figures 7, 8, and 9). For example, the Socioscientific Issues-based framework tends to focus on personal decision-making on controversial SSI. It, therefore, does not include any 'action' components on the horizontal axis (recall Chapter 2, Table 1), ending at 'take a stance.' However, in 'taking a stance,' the teachers would likely put a significant amount of work and thought into this degree of SSI engagement (including aspects found in socioscientific reasoning skills as explained through the Socioscientific Issue-based framework [e.g., Romine et al., 2020; Sadler et al., 2017; Zediler, 2014]). This provides me, as the researcher, with more ideas to frame and understand the teachers' SRSE experiences. However, the four science education frameworks reviewed in this chapter were not deemed essential at the level of the teachers participating in the Learning study. I felt that would be too much information on top of everything else being explored. As such, the science education frameworks overlaid in Figure 3 were not presented to the teachers. Nonetheless, in Learning study meetings, several SRSE enactments were 'plotted' and 'unpacked' with the axes to aid teachers in their SRSE exploration.

For example, the SSI of racialized practices of cancer research (Skloot, 2017) was used to show one way I employed Figure 3 to frame the Learning study discourse, shown in Figure 4. In this hypothetical context, an educator may be most interested in evaluating the harm caused by racialized cancer research (horizontal axis) and choose to explore those harms in terms of students' beliefs and impact on others (vertical axis, 'self' and 'other'). In Figure 4, this focus is 'plotted' (i.e., drawing a connection between the horizontal and vertical axes) as 'Lesson 1, Racialized Cancer Research.'

In this first lesson, the teacher may guide students to appreciate the negative consequences of the scientific enterprise and medical establishment's differential treatment of Black and other marginalized groups, orienting Vision III goals toward 'other' (e.g., Obermeyer et al., 2019; Skloot, 2017). Following this, the teacher may prompt the students to articulate their changing ideas about what racialized medical practices mean and look like in action, orienting Vision III goals toward self. In a subsequent lesson (labelled Lesson 2, Racialized Cancer Research in Figure 4), the same SSI and horizontal axis goal could be pursued, but this time at the level of community and environment. For the community, students could engage in an activity that deciphers how systemic influences, like funding opportunities, hold up racist practices and how those might manifest in their community (e.g., research hospitals residing in

Figure 4

Example of how multiple goals inside of Vision III were used to frame the Learning study discourse. On the horizontal axis the focus is on evaluate harm of racialized practices of cancer research. The entire vertical axis draws focus.



predominately White neighbourhoods) (Obermeyer et al., 2019). For environments, the concept of ‘environmental racism’ (Morals-Doyle, 2017) could be unpacked to show how segregated communities, in certain contexts, often have higher cancer rates among racialized people owing to the allotment of housing opportunities near polluted areas (Allchin, 2021). This example uses the same SSI and horizontal axis goal but all vertical axis orientations. As plotted in Figure 4 and discussed with Learning study participants, this exercise highlights critical characteristics and distinctions from SRSE teaching and learning experiences using different SSIs for different goals.

Importantly, this conceptual tool oversimplifies complex practices inside Vision III. Individual classes or whole units could be plotted between horizontal and vertical axis components. Overlaps could exist horizontally (e.g., components of the aquaculture vignette from Section 2.1), vertically (e.g., the racialized practices of cancer research shown in Figure 4), and non-linearly (e.g., imagine a student project on mitigating harm from climate change that is oriented toward ‘environments’ for most of the horizontal axis but personal action for the specific action the student takes). When employed in the Learning study, this was explained and made explicit that there is no ‘right’ or ‘wrong’ area in Figure 3. Instead, its utility for researcher and Learning study participants comes in trying to understand *why* specific issues, pedagogies, and understandings inhabit certain areas. For Learning study participants, it was used to highlight the diversity of potential Vision III-oriented experiences. For example, a further summary of the horizontal axis of Figure 3 and Figure 4 was made with Table 3 to support teachers’ possible Vision III exploration.

Table 3

Further explanation for the possible goals of Vision III from Figure 2. Simplified from Hodson's (2011) eight steps for socio-political action.

Possible Goals of Vision III	Hodson (2011) Eight Steps for Socio-Political Action (p. xi)
Recognizing harm	(1) "Identifying and investigating SSI"
Evaluating harm	(2) "Taking account of the beliefs, attitudes, interests and values of the various stakeholders" *and* (3) "evaluating alternative viewpoints with respect to scientific, social, political, cultural, economic, aesthetic, moral-ethical, emotional and historical considerations"
Evaluating mitigation strategies	(4) "Reaching a justifiable position on the issue and formulating a persuasive argument for it" *and* (5) "searching for solutions to any problems that arise"
Taking a stance	(6) "Choosing an appropriate and justifiable course of action"
Mitigating harm	(7) "Taking action"
Reflecting on mitigation	(8) "Evaluating its consequences"

2.5 Summary

In this Chapter, I examined four frameworks which can support SRSE, reviewed the opportunities and challenges teachers feel are associated with their implementation and used the review to provide recommendations for interventions. The intervention should include a focus on teachers' context and practice, being sustained over a period that allows for deep exploration, while in collaboration with other educators or knowledgeable others, and supported by rich theoretical perspectives. From these recommendations, I introduced the Learning study as a suitable professional development model for SRSE. Following, I discussed two theoretical perspectives from the 3-VSL I used at the level of the researcher and the Learning study participants to frame the study. At the level of the researcher, I discussed how each perspective would be used to understand teachers' SRSE understandings and enactments. At the level of the participants, I discussed how each perspective could act as a lens by which the participants plan, enact, and evaluate their teaching and learning experiences in the Learning study. In the next chapter, I introduce phenomenography as an approach to data analysis and review Learning study literature to justify the adaptions I made to the Learning study model to meet the needs of the context in which I worked.

Chapter 3. Methodology and Methods Employed

In this chapter, I will first describe the use of phenomenographic perspectives to understand the qualitatively different ways teachers understood and enacted SRSE. Literature detailing the professional development approach of Learning study will then be discussed. This includes Learning study's origins, mechanisms for prompting teacher learning, and contemporary trends in Learning study scholarship pertinent to the proposed work. This discussion will show how I drew from critical Learning study features and trends to develop a bespoke Learning study model for the present study (a full timeline is found in Appendix A). Following, one Learning study meeting will be described to get a sense of the Learning study discourse. The rest are presented in Appendix B. The data sources and data analysis are then explained. A discussion aimed at ensuring the study's rigour is presented, covering issues of trustworthiness. I close the chapter by discussing how I have situated myself in the research.

3.1 Phenomenographic Perspectives to Understand Teachers' Experiences

This study focuses on understanding teachers' experiences in a 3-VSL Learning study as they explore and implement SRSE. I am interested in how secondary school teachers understand and enact SRSE and the considerations they encounter on the way to that understanding and enactment. It is from these experiences that the variety of learning opportunities afforded by the Learning study context can be explored and then adapted and extended to other contexts (Elliott, 2012). Moreover, the relationships between these experiences have the potential to allude to the nature of SRSE uptake in this study and, consequently, the nature of teacher learning concerning SRSE. Due to my interest in the range of teachers' collective experiences, and the relationships between them, the research approach of phenomenography is appropriate. First, some onto-epistemic underpinnings of phenomenography will be discussed, including how phenomenography defines learning. I will then move on to some methodological considerations of this research tradition.

3.1.1 Onto-Epistemic Underpinnings of Phenomenography

Phenomenography is a research approach initially developed in the Department of Education at the University of Göteborg based on empirical studies from the 1970s (Marton & Booth, 1997; Säljö, 1975; Svensson, 1976). These early studies found there were a limited number of qualitatively different ways to experience a phenomenon (e.g., Bowden, 1994a; Marton & Booth, 1997), and the research specialization initially became oriented to how different ways of experiencing could be captured (Pang, 2003).

In aiming to capture different ways of experiencing through 'categories of description’ (Marton & Booth, 1997), phenomenography espouses a non-dualist ontology grounded in the principle of intentionality (Marton, 1981; Marton & Booth, 1997). This view of human cognition purports that experience is based on an internal relationship between the experiencer and the phenomenon being experienced (Hajar, 2021; Marton, 1981). This is because any distinction between “the internal (thinking) and the external (the world out there)” is rejected in phenomenography (Säljö, 1997, p. 173). The two are inextricably related through an individual’s awareness of the world. Ontologically, the relationship between consciousness and reality draws focus in phenomenography. ‘Reality’ is only what individuals can communicate based on their experience. If a phenomenon is outside an individual’s experience or awareness, it cannot be communicated.

The focus on individuals’ experience in phenomenography means that categories of description are taken from the experiencer’s perspective (Bowden, 1994b; Richardson, 1999). This second-order perspective focuses on statements of perceived reality instead of statements about reality (Marton, 1981). Marton (1986) notes this perspective had been taken before (e.g., Werner, 1948) and in some instances with widespread acclaim (e.g., Piaget's early work sought the qualitatively different ways children at various stages of development view aspects of their world). However, these studies explored variation in experience for instrumental purposes: as indicators of human development, culture, historical periods, or subcultures. What Marton (1981, 1986) argues makes phenomenography distinct in its second-order perspective-taking is that the variation in experiences can be seen to be inherently interesting (e.g., as in pure phenomenography [Marton et al., 1994]) or can be used to support individuals trying to experience a phenomenon in a new way (e.g., as seen in developmental phenomenography [Bowden, 1994a; Walsh et al., 1993]). Research of the latter kind has been more prevalent in recent phenomenographic studies (Bowden & Green, 2005; Dare et al., 2019).

Early phenomenographic research, in being primarily descriptive, was criticized for its lack of theoretical underpinnings (e.g., Säljö, 1994). According to Pang (2003), the result of this criticism was that those specializing in the tradition shifted their focus from describing differences in experience (e.g., "what are the different ways of experiencing a phenomenon?" [p.147]) to explaining the nature of those differences (e.g., "what is the actual difference between two ways of experiencing the same thing?" [p. 147]). In other words, the claim that there was a 'limited number of qualitatively different ways to experience a phenomenon' needed to be qualified and grounded concerning two components. First is the *limited* component. This is counterintuitive, given the breadth of possible human experience. Second, the *qualitatively different ways* component. What is the nature of individuals experiencing the *same* phenomenon in qualitatively different ways?

Marton and Booth (1997) put forward a theory of awareness to address both areas, drawing from Gurwitsch's (1964) structure of awareness. This theory of awareness elucidates individuals' expressions of reality, addressing elements of phenomenographic epistemology (e.g., Hajar, 2021). First, Marton and Booth (1997) argue that the reason behind there being a limited number of ways to experience a phenomenon is that there is a limited number of features that distinguish every phenomenon from another, and there is a limit to our capacity to focus on all the features simultaneously. As such, the features which are critical of an experience that are discerned characterize a specific way of experiencing that phenomenon. What features are discerned simultaneously, or brought into awareness, necessarily limits *all* ways something could be experienced based on human capacity.

Second, the structure of individuals' awareness can explain differences in individuals experiencing the same thing (Marton & Booth, 1997). Turning to Gurwitsch (1964), whose work is cited in phenomenographic research when dealing with structures of awareness (Lo, 2012; Pang, 2003), there is the focal object (or theme), those features related to the object and in which it is embedded (thematic field), and those features which are coexistent with the object without being related to it (the margin). The relationship between these elements is fixed at any instance but also dynamic at any time (Lo, 2012). As such, the qualitatively different ways of experiencing something relate not only to which critical features are discerned but also among those discerned which are in focus (the theme) and which are in the background (the thematic field, the margin) (Han & Ellis, 2019). This differing structure of awareness accounts for individual variation in experiencing the same thing. The claim that there are limited qualitatively different ways to experience a phenomenon is qualified from these underpinnings. It is based on the human capacity to be aware of critical features and the structure of that critical feature awareness.

The critical features can be further defined by what 'aspects' are being focused on in the feature and what meaning is given to those aspects. This adds depth to the *qualitatively different ways* component. These aspects are often labelled structural (what was focused on) and referential (what meaning was given to that focus) aspects (Miechie et al., 2019; Tan & Nason, 2013), though researchers have also called them 'explanatory dimensions' when explaining the results of phenomenographic analysis (e.g., Tan & Caleon, 2022).

These underpinnings provide a foundation on which phenomenography is used as a methodology. However, phenomenography also needs to address how increased awareness occurs (another component of phenomenographic epistemology). In this sense, Marton and Booth (1997) argue that the critical aspects themselves cannot be focused on or discerned without varying features of them in some way (Pang, 2003). Thus, to move from one way of experiencing a phenomenon to another, one must experience variation in critical aspects of that phenomenon, aspects which were not discerned before or of which were not made focally aware. If this new way of experiencing a phenomenon includes more critical aspects (Pang, 2009) or the critical aspects are more complex than before (Pang et al., 2006; Tan & Nashon, 2013), learning can be argued to have occurred.

Therefore, ‘learning,’ consistent with phenomenographic perspectives, can be defined as a change between qualitatively different ways of experiencing a phenomenon. In this study, it will be defined as a change between qualitatively different ways of experiencing SRSE. It is the building of teachers’ capacity to experience SRSE and their practices in more complex ways than before, to pay attention to more aspects of SRSE teaching and learning than formerly possible. A similar framing to teacher learning has been employed in earlier phenomenographic studies (see, e.g., Tan and Nashon [2013] and Miechie et al. [2019]).

To conclude this onto-epistemic portion, adding a theoretical structure of awareness and the part variation played within that structure to phenomenographic research produced two outcomes (Åkerlind, 2018). First, it extended the methodological elements of the more descriptive phenomenography of the 1980s, enhancing it analytically and theoretically. Now, phenomenography was primed to not only describe the qualitatively different ways of experiencing a phenomenon but also “how different patterns of awareness and non-awareness leads to variation” (Åkerlind, 2018, p. 951) in ways of experiencing a phenomenon (i.e., the nature of the difference). Second, the pedagogical implications of a theoretical structure of awareness and the part variation play within that structure led to the proposal of a variation theory of learning (Lo, 2012), with associated implications for education in terms of variation theory research (Åkerlind, 2018; Marton & Tsui, 2004). Focusing on the phenomenon of learning brought attention to how awareness could be utilized to encourage more advanced, complex, or disciplinary-appropriate ways of experiencing, leading to changes in learning outcomes (Pang, 2003).

Given the focus of this study on understanding teachers’ experiences exploring and implementing SRSE in a 3-VSL Learning study, phenomenographic perspectives for learning and data analysis are suitable. In capturing qualitatively different ways of experiencing SRSE and their critical aspects from a phenomenographic perspective, this study has the potential to allude to the nature of SRSE uptake and, consequently, the nature of teacher learning concerning SRSE.

3.1.2 Methodological Consideration in Phenomenography

Based on the onto-epistemic underpinnings already described, how qualitatively different ways of experiencing are captured deserves some attention. I will take up three points. First, phenomenography assumes that there are a limited number of qualitatively different ways to experience a phenomenon. As such, pooled analysis is used to capture experiences as described by the participants themselves (Marton & Booth, 1997). This is where data sources are not understood in isolation but need to be interpreted in the context of all data sources and where categories cut across participants rather than only reflecting individuals. This pooled analysis enables researchers to argue that the full range of possible ways of experiencing a phenomenon can be captured from a sample group collectively.

This is despite the fact that the same phenomenon can be experienced differently by the same or different individuals. Of course, the full range of experience is an ideal researchers strive towards (Åkerlind, 2012) – the 'full range' is a subset "that is pertinent and accessible for the sort of people being studied" (Marton & Booth, 1997, p. 121), and even that subset is fundamentally inexhaustible. Hence, phenomenographers are necessarily constrained to focus on the "critical differences in people's capabilities for experiencing the phenomena" (Marton & Booth, 1997, p. 123) and not every way, everywhere, for everybody.

Second, the demarcation of critical features of an experience into critical aspects is often used by phenomenographers as an analytic framework to aid in the analysis and utility of the categories of description (Harris, 2011; Taylor & Booth, 2015). In the context of teacher learning, Tan and Nashon (2013) used structural and referential aspects to show the nature of teacher learning, while others have used them to highlight in what ways the categories of teachers' experiences were more complex than others (Miechie et al., 2019).

Third, presenting the full range of possible ways of experiencing a phenomenon through categories of description and their critical aspects typically takes the form of an 'outcome space' (Marton & Booth, 1997). The outcome space is “the complex of categories of description comprising distinct groups of aspects of the phenomenon and the relationships between them” (Marton & Booth, 1997, p. 125). It is assumed to contain the full range of variations of conceptions emerging from a phenomenographic analysis (Taylor & Booth, 2015). In capturing the 'full range' (with the abovementioned caveat), the categories of description in an outcome space can be judged based on criteria from the onto-epistemic underpinnings already mentioned (Section 3.1.1) (Marton & Booth, 1997).

The first criterion is that the categories highlight something distinct about a particular way of experiencing (Bowden, 1994b; Matron & Booth, 1997; Richardson, 1999). These are the qualitatively different ways. The second criterion is that the categories are logically and inclusively related. Recall that phenomenography views experience as an internal relationship between the experiencer and the phenomenon being experienced (Marton, 1981). Owing to the common experience of the phenomenon, there is an assumption of structural connections (in terms of 'what' and ‘how’ the phenomenon is experienced) between different ways of experiencing the phenomenon. This means that the categories of description logically relate to each other as a rule (Marton & Booth, 1997, p. 125), most typically as a hierarchy of inclusive relationships. These relationships are the substance of increased discernment of more complex or critical aspects (i.e., in this study, learning). Third, the categories are constructed parsimoniously – recall, there are a *limited* number of qualitatively different ways to experience a phenomenon owing to our capacity to be simultaneously focally aware of various critical features (Marton & Booth, 1997).

In most phenomenographic research, the researcher thus aims to present a set of different meanings and how those meanings logically and inclusively relate. In doing so, a holistic view of collective human experience about a phenomenon is presented, characterized by the phenomenon at a particular point in time by the sample group collectively. However, in creating an 'outcome space,' divergent methodological considerations, which authors argue still hold phenomenographic onto-epistemic underpinnings, are apparent. This contributes to the development of the methodology as a whole (e.g., Åkerlind, 2018; Rovio-Johansson & Ingerman, 2016; Tight, 2016), reflecting the *use* of a methodology by researchers, including what perspectives are drawn upon, borrowed, and extended, and for what purposes.

3.1.2.1 Borrowing from Phenomenographic Perspectives. Borrowing from phenomenographic perspectives enables researchers to produce variation in methodological components while striving to maintain deeper philosophical and theoretical consistency. For example, phenomenographic terminology varies in the research literature as reflected in the depth of theoretical underpinnings employed. Some researchers explicitly label critical aspects structural and referential (Meichie et al., 2019; Tan & Nashon, 2013; Taylor & Booth, 2015), while others provide their meaning (e.g., what was focused on [structural] and the meaning of that focus [referential]) only (e.g., Tan & Caleon, 2022). Other researchers use the structural aspects to allude to a more nuanced and dynamic view of awareness (e.g., Taylor & Booth, 2015). They draw from Marton and Booth's (1997) interpretations of Gurwitsch's (1964) structure of awareness to define the boundary of 'what' was focused on, at once differentiating and relating phenomena to the contexts in which they are understood (e.g., Go & Pang, 2021).

Another example comes from how and if the categories of description are ordered (i.e., most typically as a hierarchy). This varies based on the phenomena and researchers' preferences

(Åkerlind, 2012). For example, in Tan and Nashon's (2013) study on teacher learning experiences in Learning study, their categories of description were not ordered. The authors did not wish to place judgments on the ways teachers learnt. However, the categories were still described in relation to each other by presenting critical aspects which differentiate them. In Taylor and Booth's (2015) study on secondary science teachers' conceptions of science teaching, four qualitatively different ways of experiencing science teaching were reported. They were ordered hierarchically based on the comprehensiveness of the categories. The lower order was the experience of science teaching as transferring science knowledge 'hand-to-hand,' and the higher order created a space for learning problematic science knowledge.

While both studies mentioned above reported structural and referential aspects of the categories of description, only one placed the categories in hierarchical order. The rationale behind the order "is grounded in the argument made earlier, that the categories of description denote a series of increasingly complex subsets of the totality of the diverse ways of experiencing various phenomena" (Marton & Booth, 1997, p. 126). This is a direct methodological implication of the theoretical propositions put forward by phenomenography's non-dualist ontology and structure of awareness. However, Marton and Booth (1997) also note that this hierarchy serves mainly educational purposes:

> Some ways of experiencing … are more complex, more inclusive, or more specific than others, and they coincide to a greater or lesser extent with those considered to be critical for further educational development. Thus, we seek an identifiably hierarchical structure of increasing complexity, inclusivity, or specificity in the categories, according to which the quality of each one can be weighed against that of the others. (p. 126)

Considering the educative purposes of ordering categories of description, it is understandable why Tan and Nashon (2013) chose to deviate from most phenomenographic studies while maintaining phenomenography's theoretical coherence. Explicating structural and referential aspects was done to show the nature of teacher learning by highlighting what was focused on in a particular category of description and what meaning was ascribed to that focus. Here, non-ordered relationships among the critical aspects make sense as it is difficult, and potentially troublesome, to conceptualize teacher learning as a hierarchy of complexity.

However, in Taylor and Booth's (2015) study, the structural and referential aspects were used to highlight in what ways the categories of description were more complex or comprehensive than other ones. Here, the case can be made that experiencing science teaching can be done in more complex ways and that these more complex ways are likely ‘better’ in specific contexts. Knowing these different ways, therefore, has educational utility.

Another example includes a focus on the context of phenomenographic studies. Berglund (2005) drew on components of cultural-historical activity theory (as forwarded by Vygostky [1978], Leontiev [1981], Engeström [1987, 1999, 2001, 2009, 2017], Roth et al. [2009], Roth [2010], and Langemeyer and Roth [2006]) to aid in the analysis and presentation of their phenomenographic analysis. Booth and Hultén (2003) and Hallett (2009) adopted a similar approach, where a phenomenographic analysis of learning (Booth &Hultén, 2003) and study support (Hallett, 2009) was complemented with a description of the phenomenon in context through an activity system approach (e.g., Campbell et al., 2014; De Beer, 2019; Hughes & Panzo, 2015; Jonassen & Ronrer-Murphy, 1999; Miao et al., 2009; Wei, 2019).

Berglund (2005), Booth and Hultén (2003), Hallett (2009) argued that this practice allowed variation in experience to be related to the historical, social, and cultural factors that created it. For Hallett (2009), this resulted in knowledge claims such as: “The structural and referential components of variation in student experience are predominantly influenced by mediating artifacts” (p. 146). The use of mediating artifacts alludes to the processes by which critical aspects inside specific categories of description were brought into focal awareness. This represents the inclusion of theoretical and methodological innovations in the application of phenomenography while still holding the central tenants of the research specialization. Examples in addition to activity theory have been reported (e.g., Tight, 2016).

A further example includes the data sources gathered for phenomenographic analysis. Traditionally, semi-structured interviews have been conducted (Marton & Booth, 1997), which privilege participants' utterances while other data is used for contextual information. However, several innovations in data collection can complement and add to the phenomenographic interviews as data sources (e.g., photographs [Collier-Reed, 2006] and concept maps [Yu, 2019]). Additional data sources to interviews serve to not only triangulate data (Mathison, 1988) but enrich the pool of meanings in ways that allow for more nuanced understandings of categories of descriptions and their relations. The four examples from this section highlight ways phenomenographic perspectives are being pulled and borrowed to further develop the methodology in practice. They point to some developments in phenomenography garnering contemporary attention.

3.2 Study Context: School, Participants, and Curriculum

School selection for this study was initially targeted at institutions with whom I worked as a professional development facilitator. In February 2020, 20 teachers were contacted, and snowball sampling was employed to understand BC teachers’ evolving interest and availability in participating in an SRSE Learning study (Parker et al., 2019). 22 teachers were subsequently contacted to gauge specific interest. Given the outbreak of the coronavirus disease 2019 (COVID-19) pandemic in March 2020, many teachers felt unable to participate. This led to a pool of six remaining interested teachers: two from the same school and four from four different schools. The decision was made to work with one school site if COVID-19 restrictions prevented movement between research sites.

The research site chosen was an independent secondary school in BC (Cranberry High, pseudonym). All eight science teachers from Cranberry High were invited to participate in the Learning study. Two additional teachers decided to join based on availability and their interest in the revised BC curriculum and SRSE. All the teachers shared a common interest in science education approaches which moved away from traditional teaching practices (such as didactic 'teacher talk') and deemed engagement with the study as an opportunity to further develop their teaching. The final Learning study team involved three science teachers and one school administrator. All participants were practiced educators with nine to 40 years of teaching experience. Three of the teachers were relatively new to the school (Table 4)[4]. All participants had teaching degrees.

Table 4

Teaching and school experiences of participants.

Participant	No. of years teaching	No. of years at Cranberry High	Role
Nicole	9	1	Science Teacher
Mike	27	1	Science Dept. Head
Dave	7	2	Science Teacher
Faye	40	13	Administrator

[4] Table 4 does not include racial/ethnic information about participants because of the small size of Cranberry High. This omission protects participant anonymity.

Dave and Mike had completed graduate work (earning Master of Science and Master of Arts degrees, respectively). Mike was the Science Department Head at the school, and Faye was in an administrative role overseeing all academic programming. Faye had previous experience as both a humanities and science teacher. The school environment was welcoming and collegial. School leaders were generally supportive of new initiatives and professional development programming. Teachers could apply to attend relevant conferences and workshops during teaching hours, and the school often funded these activities.

The BC science education context during the time of the study was marked by the continued rollout of a revised curriculum (Blades, 2019; BCME, 2018a), of which all teachers at Cranberry High were mandated to teach. The curriculum was gradually released for kindergarten to Grade 9 in the fall of 2016, Grade 10 in the fall of 2018, and Grades 11 and 12 subjects (e.g., Biology, Chemistry, Physics) in the fall of 2019. Full implementation was aimed for 2020 to 2021 (i.e., members of the Ministry of Education would visit schools to see that the revisions were in place) (Knaack, 2018). Beginning in the fall of 2020, this study coincided with the transition to full implementation.

The revised curriculum prioritized the development of science process skills (e.g., questioning, predicting, analyzing, communicating), which were termed 'competencies' over content (e.g., explaining atomic structure based on Bohr or Lewis models) (Blades, 2019). Both are subsumed under the title 'Learning standards' in which the content provides the context for learning competencies (Blades, 2019). The BC Ministry of Education argued for the focus on skills owing to the shifting career and technology landscape of the 21st century (BCME, 2011). They argued that scientific 'content' was more readily accessible via the Internet and technological tools, and the focus of 21st century careers on critical and creative skills required content-heavy approaches to science curricula to shift to process-oriented outcomes.

The participants in this study were obligated to teach the revised BC curriculum as part of their work at their school. The revised curriculum, as framed by SRSE, was a starting point for the Learning study. Dave, Mike, Nicole, and Faye participated in the Learning study, as detailed in the next section. They were interviewed before and after the Learning study and engaged in group and individual support meetings and knowledge dissemination efforts from August 2020 to June 2021.

3.3 The Learning Study Approach

Based on the literature review of Chapter 2, professional development to support SRSE exploration should contain: a focus on teachers' context and practice, being sustained over a period that allows for deep exploration, while in collaboration with other educators or knowledgeable others, and supported by rich theoretical perspectives. A professional development approach that captures all recommendations is the Learning study. In this research, it is employed to both support and study teachers' experiences with SRSE.

In the following section, the history and development of Learning study will be presented as well as how it is purported to influence teachers' professional development. Recent trends and connections of Learning study to SRSE will also be discussed. From this review, I draw recommendations to develop my own Learning study approach. The section closes with an explanation of how a 'concurrent-and-successive' Learning study was developed and employed.

3.3.1 An Introduction to Learning Study

The term 'Learning study' was first devised by Professor Ference Marton when he was a visiting professor in Hong Kong (Pang & Runesson, 2019). It is often described as a variant

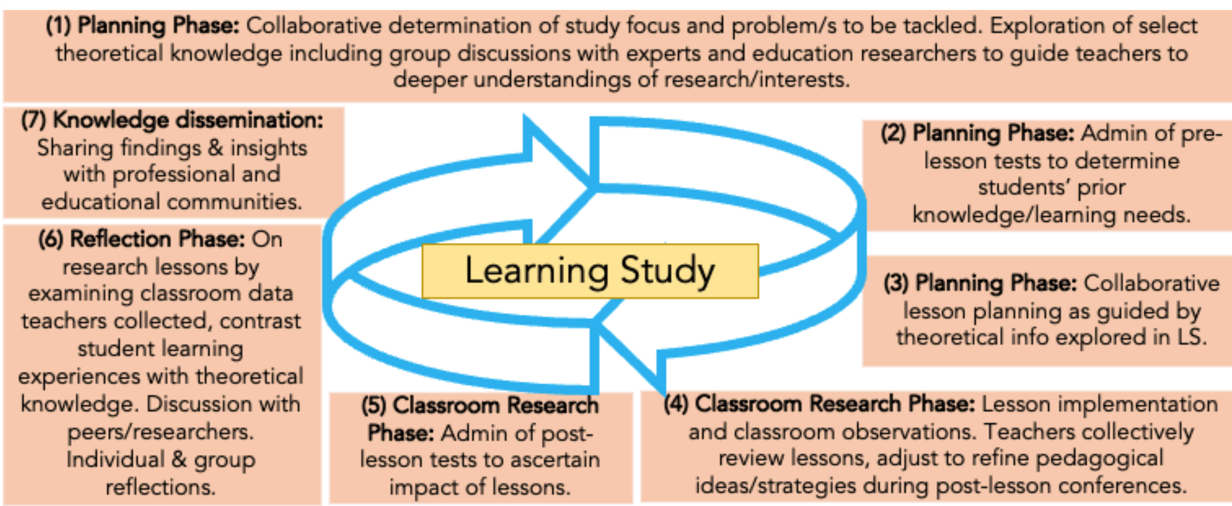
(Pang & Lo, 2012) or expansion (Pang & Runesson, 2019) of Lesson study (though that debate continues [Lewis, et al., 2019; Ko, 2019a; Wood, 2017]). *Lesson* study is a PD approach originating in Japan (Stigler & Hiebert, 1999; Yoshida, 1999). It is an investigative instructional improvement method where teachers systematically and collaboratively plan, observe, and evaluate research lessons (Lewis & Tsuchida, 1998; Lewis et al., 2004; Lewis, 2009; Lewis et al., 2009). *Learning* study builds from these features, drawing inspiration from educational design experiments (Pang & Marton, 2003; Pang, 2006) and adapting their aims of combining theory-based and systematic approaches to teacher classroom research (Brown, 1992; Collins, 1992). Indeed, a key distinction of Learning study is its focus on theoretical perspectives "to further improve instructional practice and teacher learning" (Tan, 2014a, p. 414). The theoretical perspectives ground lesson design, implementation, and reflection (Elliott, 2012; Kullberg et al., 2019; Pang & Runesson, 2019; Wood & Sithamparam, 2015).

Another distinction between Lesson and Learning study is Learning study's focus on an object of learning, or a capability to be developed by students. The justification is that "pedagogical acts should be driven by the object of learning" (Pang & Runesson, 2019, p. 164) rather than general teaching arrangements (e.g., seating organization, flipped classroom models). In this sense, the research lessons are oriented toward helping students develop the desired capability, and teaching arrangements are subordinate to this goal.

In practice, Learning studies are aimed at collaboratively determining how students can best be aided in appropriating the object of learning. Teachers share and explore disciplinary and pedagogical content knowledge and theoretical perspectives. They then examine students' prior experiences, typically through some form of pre-test or interview, aiming to define more clearly the object of learning as well as uncover design insights for their research lessons. Lessons are taught and observed by the Learning study group iteratively, resembling an action research cycle (Elliott, 2015), so that they can be analyzed and evaluated for areas of improvement. The student's learning outcomes in line with the object of learning are then evaluated by comparing pre-and post-test results. Finally, ideas and insights are disseminated to other educators about the Learning study process and its outcomes. A summary of the seven steps of a typical Learning study – shortened to 'LS' for interpretability – found in the literature is provided in Figure 5.

Figure 5

Steps of a typical Learning study (LS) cycle as documented by Tan et al. (2019a) and Tan (2017).



Through phases of collaborative and iterative planning, teaching, and reflecting, teachers explore new possibilities for instruction. They are guided to pay attention to students' learning difficulties (Fujii, 2018; Olteanu, 2017; Tan & Nashon, 2013), share collective experiences and challenge existing norms (Hervas, 2021; Ko, 2019a) and improve their instructional design processes (Bruce et al., 2016; Nilsson & Vikström, 2015). Central to Learning study is 'learning.' Teachers learn how to approach the object of learning and expand their pedagogical inventory; students learn about the object of learning in more powerful ways than they would have without the study; researchers learn about the employment of theoretical perspectives and the Learning study process more broadly (Pang & Marton, 2003). In this sense, an ideal rendering of a Learning study should touch on these three aspects of learning. Unfortunately, various constraints typically bar this goal (for a review of all learning aspects, see Kenny [2016] and Ko [2019a] for teacher professional development and Learning study, respectively). For the purposes of this dissertation (with its focus on professional development), the focus will be on the first and third aspects, aiming to inform practitioners of crucial practices supporting SRSE, and researchers and teacher-educators/professional development leaders as to processes required to support SRSE teaching, learning, and development.

3.3.2 Mechanisms of Improved Instruction

The mechanisms by which teachers improve instruction in Learning studies contain elements of practice-oriented and theory-oriented models of teacher development (Clarke & Hollingsworth, 2002; Gu & Wang, 2006). In these models, researchers contend that effective professional development occurs when there are changes in teachers' beliefs, changes in practice, and gains in teachers' knowledge which combine to improve student outcomes (Desimone, 2009). The direction of change varies across the models. Some researchers argue that (1) a change in teacher beliefs and knowledge leads to (2) a change in teacher practice and, therefore, (3) a change in student outcomes (Gu & Wang, 2006). The outcomes then reinforce or reframe the belief and, subsequently, the practice (i.e., a theory-oriented model: #1, #2, #3, #1).

Others argue that a change in teacher practice, without a substantial change in belief or knowledge, can still precipitate a change in student outcome. Should the changed practice produce favourable outcomes, teachers' beliefs are likely to change as well (e.g., Clarke & Hollingsworth, 2002; Granger et al., 2019) (i.e., a practice-oriented model: #2, #3, #1, #2).

Research on teachers' experiences in Learning studies shows that regardless of practice-/theory-oriented models, the relationships between teachers' knowledge, practice, and outcomes they deem important (e.g., student learning) are interdependent and strengthening. Learning trajectories are idiosyncratic, cyclical, and non-hierarchical. Authors focusing on improved instruction contend it stems from the interplay of developing teacher knowledge bases (Nilsson & Vikström, 2015), expanding and shifting teachers' beliefs (Tan & Nashon, 2013), fostering professional communities (Attorps & Kellner, 2017), and developing instructional resources (Morris & Hiebert, 2011).

That said, other outcomes of Learning studies are evident. Björk (2019) focused on how teachers' practical problems turn into research questions, while Ko (2019b) explored how new assessment approaches develop and are understood by participating teachers. Researchers generally argue that outcomes or processes not directly tied or following the sequence of the linear models presented above deserve focus (e.g., Lantz-Andersson et al., 2018; Yurofsky et al., 2019). These can contribute to a more nuanced and experience-based understanding of professional development 'change sequences' or 'growth networks' (Clarke & Hollingsworth, 2002) and of Learning study 'learning.'

From the above review, approaches to Learning study should have the object of student learning and theoretically enhanced cycles of classroom research at their core. Likewise, facilitators of Learning study should be conscious of the idiosyncratic, cyclical, and non-hierarchical learning teachers encounter as they work to achieve certain student learning outcomes. Recent trends in Learning study scholarship provide additional and nuanced considerations to support teachers further.

3.3.3 Recent Trends and Connections to the Proposed Work

Trends in Learning study research pertinent to the proposed work include (1) the domination of one theoretical perspective in Learning study, (2) expansions to broader and more complex objects of learning, (3) the use of Learning study in diverse contexts, and (4) the propulsion of online models. Each will be discussed in turn.

3.3.3.1 Employment of Dominate Theoretical Perspectives. A defining characteristic of Learning study is employing theoretical perspectives to support teachers' aims (Pang & Marton, 2003; Pang & Lo, 2012; Saito, 2012). The theoretical perspectives "systematically structure a teacher's understanding of his or her work in a particular context" (Stenhouse, 1975, p. 157) which aids in the planning, implementing, and reviewing of practice. Theoretical perspectives can also expand teachers' collective wisdom (Tan, 2017), support teachers' praxis (Tan et al. 2019b; Wood et al., 2015), and facilitate the production of practical public knowledge for other educators (Kullberg et al., 2019). These outcomes echo some of Stenhouse's (1975) views on the utility of theory in teacher research. Teacher research should be concerned with critiquing and extending principles of procedure accrued in professional knowledge bases that, when reviewed and reconceptualized by others, increasingly cast classrooms as learning 'laboratories' (Elliott, 2012). These principles of procedure are tied together by theoretical perspectives, which facilitates building both principles and theory in the contexts in which they were first developed and in distant classroom laboratories.

In recent years, the domination of one theoretical framework employed in Learning study has come under scrutiny (Elliott, 2019; Runesson, 2016; Tan et al., 2019b). This is because different theories, when employed in Learning studies, are underpinned by different onto-epistemic assumptions (Lo, 2016). When used in Learning studies, this diversity provides teachers with different lenses to view their teaching (Tan, 2014a). However, this will also direct teachers' attention to different things (Runesson, 2015), inevitably leading their research to focus on different outcomes.

For example, in most Learning studies, variation theory remains dominant (Pang & Runesson, 2019) – to the point where variation theory and Learning study have become virtually inseparable (Tan et al., 2019b). Based on phenomenography (Marton & Booth, 1997), the pedagogical implications of its theoretical structure of awareness, and the part variation plays within that structure, led to variation theory research. Focusing on the phenomenon of learning (Åkerlind, 2018), this brought attention to how awareness could be utilized to encourage more advanced, complex, or disciplinary appropriate ways of experiencing, leading to changes in learning outcomes (Pang, 2003) (for a summary see Section 3.1).

Though complex, the difference between phenomenography and variation theory research can be appreciated by noting that phenomenography sets out to better understand "the variation in holistic understanding of a concept and how different patterns of awareness and non-awareness of component parts leads to variation in holistic understanding" (Åkerlind, 2018, p. 951). Variation theory research takes the next pedagogical step and uses that information to plan patterns of variance and invariance with the goal of guiding others to certain ways of experiencing (e.g., to more disciplinary appropriate ways or towards an object of learning) (Marton & Tsui, 2004; Lo, 2012).

Brain research theories (Tan et al., 2019b) and others (Martin & Towers, 2016) have been recently employed in Learning studies. However, more theoretical perspectives are warranted in view of theories' inherent limitations regarding how and what teachers focus on in their practice (Lo, 2016). Additionally, a central role of theoretical perspectives in teacher research is to give teachers “a common vocabulary and a syntax of theory” (Stenhouse, 1975, p. 157) as a way for them to hold together conversations on educative problems and innovations. In this light, the employment of additional theories in Learning study can further its democratic aims in line with action research (Elliott, 1991) and avoid the hegemony of one theory. “Teacher collaborative research that is grounded in a ‘democratic model’ of reasoning needs to be informed by [theory]” (Elliott, 2019, p. 788) so that all members can build on shared and emerging knowledge, experience, and skills. Confining Learning studies to one theoretical perspective hinders certain potentials for the growth of the approach and the theory.

Exploring the second-order perspectives of teachers using diverse theories to inform instruction is encouraged as the pedagogically significant similarities and differences of each can be examined, refined in different contexts, and continually examined (Elliott, 2012). In this research, the use of 3-VSL, as described in Sections 2.1, 2.2, and 2.4, provides suitable theoretical perspectives for teachers to systematically structure their understanding, develop a shared language, and tie together potential principles of procedure in line with SRSE.

3.3.3.2 Developing Literacies as an Object of Learning. Learning study has also come under critique for focusing on too narrow and simple objects of learning (Pang & Runesson, 2019) where minute and specific concepts or content are pursued. Given the extensive time researchers and teachers devote to Learning study, its value can be questioned given the seemingly ‘trivial’ results (Dahlin, 2007). As such, attempts have been made to expand objects of learning in Learning study to new areas (e.g., Olander & Sandberg, 2013; Pang, 2010; To & Pang, 2019). As an example, developing students’ financial literacy (Pang, 2010, 2019) or students’ awareness of literary genres (To & Pang, 2019).

Practically, this is desirable because objects of learning need not solely be predicated on what core concepts or principles are appropriate for the discipline. Rather, considerations of objects of learning should lie with the Learning study group and what they deem most important and challenging to warrant support for student learning. Indeed, objects of learning can be pitched at what students are expected to learn across a series of lessons, a semester, and even an entire program of study (Maybee et al., 2018). More expansive learning objects allow more complex learning to draw aim, likely requiring more lessons taught and more effort in planning.

Broadly, increasingly complex learning objects can contribute to students 'generative learning' capabilities (Pang, 2019; To & Pang, 2019), or the application of multiple concepts to develop a generic capability. In the case of Pang (2010, 2019), this was developing students' financial literacy; To and Pang (2019), developing students' awareness of literary genres.

In the view of SRSE, multiple concepts embedded in learning science, learning about science, doing science, and engaging with socio-political action need to be integrated as each Vision of scientific literacy (i.e., from 3-VSL) forms and supports the others (Hodson, 2011; Sjöström et al., 2017). This focus on domain-specific literacy under the umbrella of generative learning, that is, where the application, synthesis, and integration of learning in one context prepares learners for learning in new contexts (Holmqvist et al., 2007; Marton, 2006), is well situated in existing 'scientific literacy' scholarship (e.g., Aikenhead's [2007] Vision I-II of scientific literacy or Ziedler's [2007] "Vision 10.41" [p.76]). SRSE, as expressed in this study, requires more complex and more broadly defined objects of learning.

Drawing from Pang (2019) and To & Pang (2019), literacy-focused learning objects can take more lessons to study (e.g., 16 lessons in one Learning study were proposed in Pang's

[2019] work). Therefore, Learning studies aiming at 'literacy' have pragmatic implications. They need to be planned in view of the number of lessons, and therefore, teacher support required.

3.3.3.3 Learning studies in diverse contexts. Learning studies have been conducted in numerous countries, in several content areas, and with various foci since the inception of the approach in 2003 (Pang & Marton, 2003). The majority of Learning study literature originates in Sweden (e.g., Björk, 2019; Björkholm, 2014; Martensson & Hansson, 2018; Thorston, 2015; Vikström et al., 2013) and Hong Kong (e.g., Ko, 2019b; Lo et al., 2006; Pang, 2010), though Canadian contexts are being increasingly explored (Miechie et al., 2019; Royea & Nicol, 2019; Tan, 2018). Diverse context exploration is important for the continued propulsion of Learning study as education system-specific norms and regulations necessarily impact the approach. As an example, Tan et al. (2019a, 2019b) have used online formats for lesson discussion and teacher grade-band groupings to accommodate some of the nuances of the Canadian education system. Likewise, Martensson and Hansson (2018) have pulled from both Lesson and Learning study designs to create 'subject didactic groups,' required in their context to make collaborative efforts integrated and sustainable within Swedish teachers' everyday work. The present study's positioning in Canada requires similar modifications, which will be detailed below.

The focus of Learning studies ranges from creative writing (Thorston, 2015), technology (Björkholm, 2014), mathematics (Björk, 2019; Martensson & Hansson, 2018; Royea & Nicol, 2019), economics (Pang, 2010), languages (Ko, 2019b), science (Attorps, & Kellner, 2017; Miechie et al., 2019), and beyond (Pang & Runesson, 2019). In each, foci on student learning outcomes (e.g., Lo et al., 2006), teacher learning outcomes (e.g., Björk, 2019), or connections between the two (e.g., Pang, 2010, 2019) is most often forwarded – though first-order researcher learning is apparent as well (see Tan [2014b]). Student learning outcomes generally revolve around students' mastery of the object of learning, for example, conceptual knowledge required to understand the colour of light (Lo et al., 2006), distillation, and Newton's Third Law (Linder & Fraser, 2009; Fraser & Linder, 2009). Teacher learning outcomes can vary widely, including how practical problems develop into research questions (Björk, 2019) or understanding case-specific processes by which teachers learn (Martensson & Hansson, 2018). The connections between teacher learning and student learning are also apparent. Pang (2010, 2019) explored how teaching choices from the perspective of variation theory influenced student learning, involving which patterns of variance and invariance should be pursued. The current study spotlights teacher learning outcomes in science education contexts.

Within this focus, Vikström et al. (2013) explored secondary science teachers' knowledge production in a Hong Kong variation theory-framed Learning study focused on solution chemistry. Critical aspects, or what students needed to learn for students to appreciate the object of learning, were forwarded. Vikström et al. (2013) argued that showcasing these aspects was important so other educators could use them as resources in novel situations. Kullberg (2010) and Runesson and Gustafsson (2010) found that teachers could adjust recommendations of critical aspects from one Learning study to new contexts. These results highlight the importance of attending to critical aspects and making pedagogical choices that might support their exploration known. This is salient when approaching ill-defined and complex learning objects. This, in turn, compels Learning study researchers more generally to make aspects central in the design, implementation, and progression of student learning for any – variation theory-framed or otherwise – Learning study explicit. They can serve as inspiration for future adaptations (e.g., Elliott, 2012).

Tan and colleagues have explored teacher outcomes in science education contexts. Tan and Nashon (2013, 2015) explored the nature of teacher learning and how teachers collaboratively approach the challenges of a new curriculum in a Singaporean Grade 10 genetics Learning study. From the same overarching research program, Tan (2014a) and Tan and Caleon (2016) delved into the Learning study process. The former explored how learning theory shapes the discourse of collaborative meetings and the latter how the problem-finding process in Learning study can be improved. Miechie et al. (2019) and Tan (2018) explored how in-service teachers crafted objects of learning in science Bachelor of Education courses and how in-service teachers dealt with the challenges of the Learning study process and discourse, respectively.

Collectively, these research projects point to the suitability of using a Learning study to understand teacher learning outcomes in science education contexts and contexts undergoing curriculum reform. Additional Learning studies in science education contexts provide similar support. Examples include a focus on teaching and learning biology and mathematics in primary school (Attorps & Kellner, 2017), forces, motion, and solution chemistry in secondary science (Nilsson & Vikström, 2015), ions and ion formation (Nilsson, 2014), genes and traits (Olander & Olander, 2013), developing secondary school students' knowledge and argumentation skills of what constitutes scientific theories (Holmqvist & Olander, 2017), evolution (Bravo & Cofré, 2016), particulate concepts of matter (Vikström, 2014), and elements of pedagogical content knowledge (Schneider, 2019).

The above studies provide many instances and opportunities to extend knowledge about teacher learning, the employment of theoretical perspectives, and the Learning study process. Importantly, many of the science education focused Learning studies highlight the importance of collaboration among members to learn about their objects of learning and how best to pursue them (e.g., Attorps & Kellner, 2017; Olander & Olander, 2013; Vikström, 2014). Likewise, the work of Tan et al. (2019a, 2019b) is critical as they document Canadian Learning studies *in* schools rather than university classrooms (e.g., Meichie et al., 2019; Royea & Nicol, 2019). The importance of fostering collaboration and Canadian Learning study modifications (e.g., grade-band groupings) are considerations used to design the Learning study employed in this study.

3.3.3.4 Online and Mixed Formats. Unsurprisingly, effective online professional development should follow many of the central tenants of effective face-to-face professional development (Yurkofsky et al., 2019). Teachers should be thoughtfully supported in a sustained manner, the professional development should be job-embedded yet flexible to ensure sustained engagement, and teachers should be prompted to reflect on their practice and engage in collaborative discussions that challenge beliefs and can lead to new understandings (Huang et al., 2021; Sancar et al., 2021). However, how these tenants practically play out over Zoom, Skype, Google Hangouts, FaceTime, and the myriad other ways of engaging teachers in online professional development (e.g., Massive Open Online Courses), in conjunction with a vast array of teacher professional development models, provides exciting paths for educational research.

This large body of literature has grown larger by the onset of COVID-19 pandemic and global shifts in education to online formats (Di Pietro, 2020). In Lesson and Learning studies specifically, an entire issue in the *International Journal for Lesson and Learning Studies* was dedicated to the topic in 2021 to highlight for researchers, leaders, and learners current approaches to Lesson and Learning studies occurring in the field (Weaver et al., 2021). This issue was a response to school closures and limits on person-person gatherings as spurred by COVID-19 restrictions (Di Pietro, 2020). In that special issue, Lesson study over Learning study drew focus, and online Lesson study literature has subsequently dominated (e.g., Holden, 2022).

As it pertains to this study, which appears to be one of the first online Learning studies, definitions central to the type of online format pursued and assistive technologies employed deserve attention. This foregrounds some of the choices I made when the Learning study in this dissertation was forced online midway through the study period. It also shows how my choices parallel scholarship in the field during the same period (shown in Section 3.3.4). Given space constraints, I direct the reader to literature which explores how online environments might affect teacher professional development-based collaboration (Hrastinski, 2021; Stokes et al., 2020), the effectiveness of the Lesson study approach (Goei et al., 2021; Suh et al., 2021; Widjaja et al., 2021), and the divergent roles of the facilitator or knowledgeable other (Calleja & Camilleri, 2021; Weaver et al., 2021).

The online variants of Lesson study, which can be assumed to be true for Learning study, include (1) partly assisted, (2) mixed, (3) fully online, and (4) hybrid models (Huang et al., 2021). The partly assisted model employs technology to modify some components of a traditional Lesson/Learning study, such as using videos over live observation to view research lessons (Skultety et al., 2017). The mixed model employs both face-to-face and online components, including, as an example, the use of video-recorded lessons with face-to-face meetings (Stokes et al., 2020) or a combination of video meetings, face-to-face meetings, and video-recorded and live lesson observations (Cooper et al., 2011; Vikström, 2014). The fully online model is, as the name describes, and has the added benefit of connecting Lesson/Learning study groups across different contexts, cultures, and nations (e.g., Widjaja et al., 2021). The hybrid model employs a learning management system (e.g., Canvas) that can support any of the online variants already mentioned (e.g., Joubert et al., 2020).

Assistive technologies are alluded to by the online model pursued. Spaces teachers can collaborate, share documents, video chat, and house video recordings are necessary. Technologies to populate these spaces are required (Weaver et al., 2021). When working with teachers, many are likely to have their own preferences for these technologies, and/or schools or school districts have provided them to teachers for their use (e.g., Huang et al., 2021). Given the current review, technology is meant to support and enhance the typical Lesson or Learning study process, not change it in fundamental ways. Most commonly, this includes the use of video-recorded lessons for discussions and reflections (Huang et al., 2021; Widjaja et al., 2021) as well as video-conferencing software (Zoom, Google Hangouts) or whole digital ecosystems (Microsoft Teams) to organize meetings, collaborate, plan, and reflect. Huang et al. (2021) provide a list of technology organized by online model for each step in a typical Lesson/Learning study (Figure 1, p. 113) as recommendations.

3.3.4 Employment of the Learning Study: The Concurrent-and-Successive Model

This section outlines the steps of the Learning study model I employed in more detail, adapted from Tan and Nashon (2013) and Tan et al. (2019a, 2019b), and based on recommendations from the above review. In this section, I will also discuss other adaptations to my model based on the study's context.

To begin, it is important to characterize a 'typical' Learning study. The main steps are summarized in Figure 5 above (Tan, 2017; Tan et al., 2019a) and given more detail in Section 3.3.1. Generally, broad phases of planning, classroom research, and reflection provide direction for any Learning study (Tan et al., 2019b). Within these phases, some steps might occur concurrently or be revisited during iterative cycles (Lo et al., 2006; Pang, 2006; Wood & Sithamparam, 2015) or due to study context (e.g., Tan & Amiel, 2022). Focusing on what each member does during each phase, in most Learning studies, educators collaboratively devise one object of learning, one lesson (which can take multiple classes), taught in one course, with every member teaching the research lessons (e.g., Tan & Nashon, 2013). The model I have developed maintains the broad phases (planning, classroom research, reflection) but differs in key ways.

I have termed the Learning study model I created for this research the 'concurrent-and-successive Learning study model.' It is summarized in Figure 6. The current-and-successive model was developed to accommodate the membership of teachers as well as their course schedules. In this model, each teacher contributed to planning and evaluating objects of learning, lessons, and student data. This is represented in Figure 6 by the 'all' heading (green) and 'dashed' boxes. However, every teacher did not teach every lesson. Instead, each teacher had their own research lessons and objects of learning they were responsible for. This is represented by each participant's name and associated colour in Figure 6. The approach was still held together by an overarching focus (i.e., SRSE); however, each teacher had a different object of learning based on their own interests and the courses being taught. The Learning study model is concurrent in that individual research lessons under a broader theme were planned simultaneously. It is successive in that once one set of research lessons was complete and evaluated, another began. Importantly, Figure 6 tries to simplify and serve as inspiration for a complex process. The entire timeline for the Learning study presented in this research can be found in Appendix A.

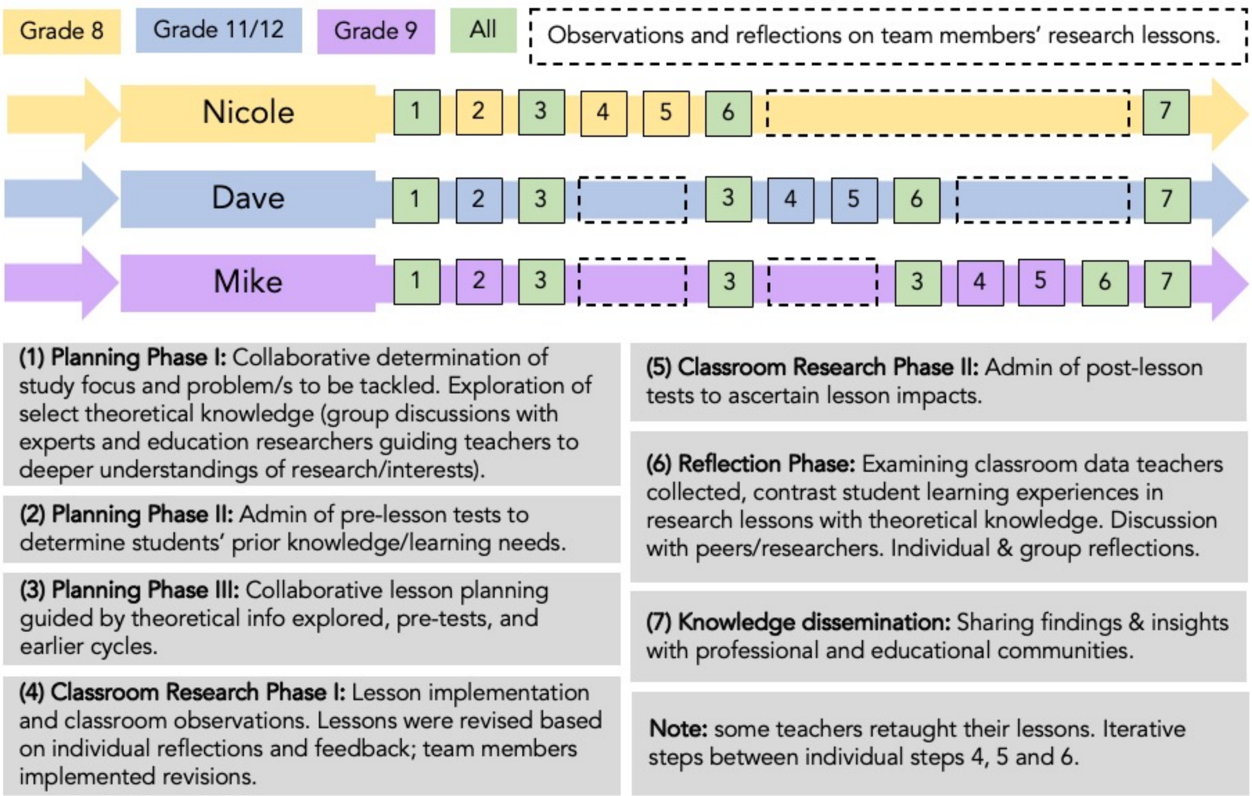
As implemented in this study, the concurrent-and-successive model contained three different lesson series, in three different courses, with three different objects of learning, at three different time points throughout the year. As an example, all the teachers contributed to the planning, observing, and reflecting of the first teacher's research lessons (Nicole, yellow in

Figure 6, with steps one to six lasting 14 weeks), and favourable practices identified were used as a basis for the second teacher's research lessons (Dave). Following, all teachers were involved in the planning, observing, and reflecting on the second teacher's research lessons (Dave, blue in Figure 6, with steps one to six lasting 25 weeks), and favourable practices identified were used as a basis for the third teacher's research lessons (Mike, lavender in Figure 6, with steps one to six lasting 27 weeks). Importantly, these iterative cycles drew focus on what students were learning as well as the teaching strategies employed (Pang & Runesson, 2019). Though the teachers' pedagogies drew attention in lesson observations, these acts were not separated from student learning. The two were examined together (e.g., Tan et al., 2019b).

Learning studies have been conducted that report on using research lesson 'products' (e.g., pedagogical insights) for teaching outside of research lessons, including across Grade bands or classes (Attorps & Kellner, 2017). Learning studies have also been documented where groups of teachers engage in successive Learning studies under a common educational goal with the same members over several semesters (Vikström, 2014). However, the 'concurrent-and-successive' model, which contains multiple Learning study cycles with different but co-authored objects of learning occurring successively, seems novel in extant Learning study literature. A summary of individual teacher Learning study activities is provided in Table 5. Table 5 shows the individual teacher Learning study activities, including when each Learning study phase was directly explored. Comparing the numbered steps of the Learning study model detailed in Figure 6 with the dates of Table 5 provides a glimpse of the intensity and scope of this Learning study approach as implemented in this research.

Figure 6

The concurrent-and-successive Learning study model implemented in this research. It is concurrent in that individual research lessons under a broader theme were planned simultaneously. It is successive in that once one set of research lessons was complete and evaluated, another began.



In the implementation of the model, subsequent meetings followed a rough schedule to ensure a timely progression through the Learning study given teachers' prior commitments and the fluid nature of school-based work during a pandemic. The contents of the meetings were always planned in view of the meetings prior, remaining responsive to the teachers' needs, readiness, and school-based interruptions. Remaining responsive to the teachers' needs produced two intertwining additions to the concurrent-and-successive model: (1) moving Learning study phases online due to COVID-19 restrictions and (2) additional support.

A mixed (i.e., employing both face-to-face and online components [Huang et al., 2021]) Learning study model was developed ad-hoc to the concurrent-and-successive model owing to shifting COVID-19 restrictions. Various ‘waves’ of COVID-19 infections occurred during the study period as population-based infections grew and subsided. Restrictions on meetings and observations had to be put in place following rising infections.

Recommendations from the *International Journal for Lesson & Learning Studies’* online special issue came out after the study was designed and near the tail-end of implementation (Huan et al. [2021] in April 2021). In this regard, scholars were quick to identify possibilities and challenges of shifting Lesson and Learning studies from purely face-to-face to online, mixed, partial, and hybrid models (each model has been explained in Section 3.3.3.4). For example, Huang et al. (2012) and others (Calleja & Camilleri, 2021; Goei et al., 2021; Hrastinski, 2021; Suh et al., 2021; Weaver et al., 2021; Widjaja et al., 2021) demonstrated that teachers’ collaboration and development of research lessons could be facilitated via video conferencing software (such as Zoom, Skype or Google Hangouts). Similarly, lesson observations could be uploaded to information management systems and observed at later times, also discussed using the same video conferencing software. These online considerations from the Lesson and Learning study field parallel the choices I made in transitioning the Learning study online.

Since my work was underway before the publication of the online special issue, I drew inspiration from literature detailing online professional development practices which were already available (Cooper et al., 2011; Skultety et al., 2017; Stokes et al., 2020; Yurkofsky et al., 2019) as well as the teachers’ preferences (e.g., Weaver et al., 2021).

Table 5

Individual teacher Learning study activities and Learning study implementation.

Learning study phase	Dates (academic year 20/21) and Cycle		
	Nicole (Cycle 1)	Dave (Cycle 2)	Mike (Cycle 3)
(1) Planning Phase 1 Determination of problems to be tackled; exploration of SRSE-specific information; initial objects of learning formulated	31 August 17 September 3 October	31 August 17 September 3 October 8 October	31 August 17 September 3 October 8 October 5 November
(2) Planning Phase 2 Pre-tests to determine students' learning needs	6 October 8 October	30 October 5 November	14 December
(3) Planning Phase 3 Collaborative lesson planning and solidification of objects of learning based on student data and previous Learning study cycle insights	30 October 5 November [b]	17 December [b] 12 January [b] 21 January [b]	14 December [b] 12 January [b]
(4) Classroom Research Phase 1[a] Teachers taught their research lessons; researchers and other members observed; lessons revised based on individual reflections and feedback; team members implemented revisions	19 November [b] 23 November [b] 24 November [b] 26 November [b] 30 November [b]	15 January [b] 26 January [b] 2 February [b] 16 February [b] 18 February [b] 22 February [b]	11 February [b] 16 February [b] 17 February [b] 18 February [b] 19 February [b] 22 February [b] 23 February [b] 25 February [b] 2 March [b] 4 March [b]
(5) Classroom Research Phase 2[a] Post-tests and check for understanding to ascertain student learning	30 November [b]	22 February [b]	4 March [b]
(6) Reflection Phase[a] Teachers individually reflected on student learning and teaching; post-lesson conferences with researcher; post-lesson conferences with team members	23 November [b] 26 November [b] 8 December [b] 12 January [b] 23 February [b] 5 March [b] 1 April [b]	2 February [b] 23 February [b] 1 March [b] 5 March [b] 1 April [b]	23 February [b] 25 February [b] 5 March [b] 1 April [b]
(7) Knowledge Dissemination Teachers shared their experiences	21 January [b] June	June	June

[a] Iterative cycles of teaching included both the classroom research and reflection phases

[b] Meeting conducted online or mixed. Teachers in the school were still able to meet in person but physically distanced

Specifically, this mixed Learning study model (in addition to being concurrent-and-successive) employed both face-to-face and online components, including the use of video-recorded and live lesson observations and video and face-to-face meetings. Learning management systems (e.g., Canvas) to house documents, meeting schedules, and videos were not employed owing to the swift onset of restrictions (e.g., Joubert et al., 2020). The choice of technology was based on teacher preference. Zoom was the common video-conferencing software; Google Docs was used by the teachers to share their lesson outlines and collaborate on shared documents – as was common at Cranberry High – and PowerPoint was used to structure meetings by providing general outlines. These practices are common in mixed online Learning/Lesson study models (e.g., Calleja & Camilleri, 2021; Goei et al., 2021; Hrasinkski, 2021; Isoda et al., 2017; Koutsouris et al., 2017; Suh et al., 2021; Weaver et al., 2021; Widjaja et al., 2021).

Coupling the concurrent-and-successive model with restrictions in meetings brought on by the pandemic (e.g., reduced spaces to meet, times to do so, and personnel who could attend) meant that more individual support for teachers was required. While group meetings were necessarily restricted to the Learning study steps mentioned above (Figure 6), the logistics and minutia between these steps – such as finalizing the survey instruments, initial analysis of student data, lesson-specific resource acquisition, and finishing touches on PowerPoints or other projects – meant that the teachers required further support in the form of individual meetings with me as the researcher-facilitator. These meetings were subsequently termed 'Individual Support' meetings or ISM. The ISMs served as a space to check in with individual teachers about their wants and needs throughout the study. Amendments could then be made accordingly. Likewise, the ISMs acted similarly to interviews in that one-on-one understanding of teachers' experiences learning about and enacting SRSE could be captured.

3.4 Method

I will describe an example of a Learning study meeting to illustrate the collaborative nature of the discourse. Every meeting is narratively described in Appendix B. In totality, they demonstrate how I pulled from the literature reviewed in Chapters 2 and 3 to support teachers' exploration of SRSE. They also showcase and make transparent the methodological choices, deliberations, and connections I made, in collaboration with the Learning study members, throughout the qualitative research process. This addresses many concerns related to trustworthiness criteria as described by Guba (1981) and Lincoln and Guba (1985), which are addressed in Section 3.7. I chose to present Group Meeting 2 because it exemplifies the messy, collaborative, and research-informed nature of Learning study meetings (Tan, 2017).

3.4.1 A sample of a Learning study meeting: Group Meeting 2

Group Meeting 2 came after the introduction of the study (see Appendix C) and SRSE. To begin the meeting, I provided a summary of the 3-VSL and the theoretical perspectives distilled to frame the Learning study (drawing from Sections 2.1, 2.2, and 2.4). I also allotted a third of the stipulated meeting time to honour the teachers' effort reading Hodson (2014) and Levinson (2018b) – both resources to explore possible SRSE interpretations. I deemed it important to recognize the work the teachers were putting into the Learning study and used the conversations developed from the readings as a guide for the remainder of the meeting. In this discussion, the teachers brought up the 'harshness' of Hodson and his 'militant Hodsonian activism' (this point will be described in Chapters 4 and 5). Levinson (2018b) was described as a 'softer Hodson,' and the teachers initially moved away from these more 'radical' science education ideas.

In this discussion, Faye made the case for Hodson's inclusion in the BC curricula, reiterating Hodson's argument that students are unlikely to engage in action for what they believe in, partly because they have never been taught. The group then wrestled with the question if 'promoting action' was in the purview of a science teacher and when and for what topic that would be appropriate. To draw guidance, the teachers spent a large part of this discussion highlighting how different science competencies from the curriculum could be matched with the arguments put forward by Hodson and Levinson. For example, a competency in the BC curriculum is that students will "implement multiple strategies to solve problems in real-life, applied, and conceptual situations" (BCME, 2018c). Based on this competency, the teachers began to form connections between the curriculum and the arguments Hodson and Levinson were making.

I then gave time to reflect on the 3-VSL. Specifically, I encouraged the teachers to focus on their own past science education experiences (i.e., the goals they perceived to be most pursued in their science learning) and their science education intentions (i.e., the goals they pursued in their own classrooms) in relation to the intentions of each Vision (e.g., Vision I aiming to produce knowledgeable non-specialist citizen; Vision II, knowledgeable area-specific professional; Vision III, contributors of care to self, others, and community). They expressed their learning of science (as students) as primarily aligned with Vision I, while their current science teaching was a mix between Vision I and II. The teachers expressed that they felt the need to strike a balance between preparing students for future science coursework *and* being citizens requiring scientific understanding.

Following, the teachers' conversation returned to discussing the importance of student action and responsibility, as forwarded by Hodson and Levinson. The teachers brought up questions regarding who decides what ‘responsible’ is and which topics are most appropriate to be responsible for. Both lines of discussion brought to the fore teachers’ beliefs and values about science education. This was intentional and used to give “teachers a chance to bring up, discuss, and perhaps reconcile competing goals or visions of education” (Lewis & Tsuchida, 1998, p. 16). As forwarded by Lee and Witz (2009), this practice treats teachers’ initial conceptions as invitations to new practice rather than barriers; and to be sure, the initial incendiary tones regarding the readings stoked the flames of engagement for the meeting.

To close the meeting, the teachers indicated the topics they were most interested in pursuing based on their course schedule and the scope and sequence of the year. Mike chose climate change for Science 9. He had taught a climate change unit the year before, focusing on technological innovations that could ameliorate the crisis. He felt the idea of ‘technology is the solution’ was one-sided and, therefore, disingenuous. Mike wanted another crack at the unit from an SRSE lens. Nicole forwarded the COVID-19 pandemic for Science 8. Science 8 covers epidemics and pandemics to introduce concepts about viruses and bacteria. Nicole felt the confluence of COVID-19, the curriculum, and using SRSE to keep students safe was a logical choice for her classes. Dave remained undecided on a topic. However, he felt that his Environmental Science class or Advanced Placement (AP) Environmental Science class were suitable courses to brainstorm a topic.

3.5 Data Sources

Data were collected from various sources (e.g., 35 meetings, 22 research lessons, and 60.5 hours of audio-video recordings). Data sources included transcripts of individual teachers' semi-structured interviews conducted at the beginning and end of the study (n=8, 10.75 hours total, transcribed verbatim), audio-video recordings of all group (n=11, 15 hours total, transcribed verbatim) and individual support (n=15, 12.75 hours total, transcribed verbatim) meetings, lesson observations (n=22, 21 hours total, field notes and audio-video recordings), and artifacts of teachers' work (lesson plans, handouts, PowerPoint presentations). A summary of these sources per participant is found in Table 6.

Meeting notes, emails, and handouts I prepared (e.g., an observational prompt document to structure research lesson observations and post-lesson conferences [Appendix D]) recorded the flow of the Learning study, serving as a record of what was intended and what occurred during meetings. I also kept detailed field notes and used a researcher's journal to record evolving ideas, articulating my pre-understandings and noting their change at regular intervals, documenting peer debriefing meetings and suggested shifts in my study, and more general introspection to practice reflexivity (Guba, 1981). The range of data sources helped stimulate the recall of past meetings. For example, audio-video recordings were watched while reading transcripts, referring to field notes and my research journal (e.g., descriptions of all research lessons Appendix E, F, G). Finally, the varied data sources were constantly referred to and laid in relation to each other to integrate the diverse sources. This served to create a 'pool of meanings' focused on the collective experience of the Learning study (Marton, 1986) while maintaining enough contextual detail to ensure a faithful interpretation of those meanings (Bowden, 1994a). This approach also represents how I triangulated the varied data sources (Mathison, 1988).

Table 6

Data sources per participant of the Learning study.

	Pre/Post Interview	Group Meeting Videos	Lesson Observations	Teacher Artifacts
Nicole	✓	✓	n=6	✓
Dave	✓	✓	n=6	✓
Mike	✓	✓	n=10	✓
Faye	✓	✓	x	x

Note. Data sources not collected: x Collected: ✓

3.5.1 Use of Interviews in a Phenomenographic Approach

Consistent with the phenomenographic approach, teachers' utterances were used as the main source of data to construct the categories of description (outcome of the analysis). In my study, apart from the use of interviews, which is the dominant method of data collection in phenomenographic studies (e.g., Åkerlind, 2005; Booth, 1997), the ISMs also acted like a variant of interviews. These meetings were focused one-on-one conversations between the teacher-participants and I, where the participants shared their experiences understanding and enacting SRSE. Given their number and interview character, it is important to describe how these meetings, as well as the interviews generally, were approached.

Though variation in how interviews are conducted in phenomenographic research is observed (e.g., length of time taken), interviews are "the open explorative form of data collection" (Svensson, 1997, p. 162) which ensures participants can "choose the dimensions of the question they want to answer" (Marton, 1986, p. 42), consistently. This allows participants to accurately disclose their relationship to the phenomenon being studied (Anderberg et al., 2008; Bowden, 1994a). This works to guard against the introduction of the researcher's ideas about the phenomenon entering the data pool (Bowden, 1994a), avoiding potentially self-fulfilling prophecies (Francis, 1993). As such, open-ended and semi-structured interviews are often employed (Ashworth & Lucas, 2000; Marton & Booth, 1997), as in this study. Likewise, all ISM had planned questions I developed to best support teachers. These held the deep and open character of typical phenomenographic interviews (Booth, 1997). Deep in the sense that discussions were followed until a mutual understanding of utterances had been reached between me (the interviewer) and the teachers (interviewee) and open such that structure had been planned, but that interesting and unexpected lines of reasoning could be followed (Booth, 1997).

Each Learning study group member participated in a pre-Learning study interview. Three were conducted in September and one in October. Each interview lasted between one and one-and-a-half hours, allowing them to be both deep and open. The first half of the interviews dealt with teachers' backgrounds, previous science education experiences, and memorable teaching and learning instances. It aimed to explore teachers' beliefs about good science teaching and learning practices. These questions were valuable, allowing the unique characteristics of individuals to be identified, later contributing to the contextual interpretation of participant utterances (Ashworth & Lucas, 2000; Tan & Caleon, 2022; Tan & Nashon, 2013).

The second half of the interviews dealt with teachers' initial understandings of SRSE and what challenges and opportunities they perceived it might entail. These questions were pivotal for the Learning study as 'call-backs' could be made to highlight growth or shifts in topics/pedagogies pursued, challenges overcome, and opportunities experienced. For example, the first interviews revealed a moniker for socially responsible science education the teachers had been using: socially *irresponsible* science education. The simple addition of two letters to SRSE served as a fruitful base for future data interpretation.

Some questions in the interviews were modified and adapted from other sources (e.g., Tan & Amiel, 2022; Meichie et al., 2019; Pang, 2006). Detailed notes and reflective journal entries were kept following all interviews. Thorough data analysis (e.g., full verbatim transcription) did not begin until after the Learning study was complete. This practice followed Sandberg's (2005) guidance, aiming to avoid premature interpretations that might bias analysis.

The final interviews were between April 26th and May 11th. The interviews enabled clarification questions from Group Meeting 11 based on the reflective prompt document (Appendix H). Questions specifically probed for shifts in understanding of SRSE, how best to enact it, challenges teachers encountered, and Learning study features most supporting or hindering their learning. Callback's to the first set of interviews were explicit, often asking teachers to comment on verbatim portions of the first interview. For example, in the first set of interviews, teachers were asked to list factors influencing their use of SRSE in the classroom. In the second set of interviews, those factors were listed for the teachers to comment on now that the Learning study was complete.

Nicole, Dave, and Mike engaged in five, six, and four ISMs, respectively (Appendix B). In June, the first set of interview transcripts was distributed to the interviewees and the second set throughout the remainder of the calendar year. A verbal summary of key points was provided during subsequent meetings. This served to check for accuracy in my interpretations of their utterances or what Creswell (1994) refers to as member checking.

3.6 Data Analysis

The primary outcome of phenomenographic research is categories of description which define the qualitatively different ways a phenomenon is experienced (Marton & Booth, 1997). In this section, the analyses of teachers' experiences are described to show how phenomenographic perspectives were borrowed to construct the categories.

3.6.1 Analysis of Teachers' Experiences

The analytic process was framed by borrowing phenomenographic perspectives as detailed by Taylor and Booth (2015), Tan and Nashon (2013), and Han and Ellis (2019), primarily based on detailed accounts provided by members of the Warburton Symposium (Bowden & Walsh, 1994) and Marton and Booth's seminal text (1997). First, verbatim transcripts were made of all interviews, group, and ISMs. This process can be seen to 'kick start' a phenomenographic analysis as meanings in the text began to emerge through a detailed listening and relistening of participant utterances via recordings. As Ashworth and Lucas (2000) describe, this initial listening served to accurately reflect the participants' emotions and emphases, ensuring anything that might affect the interpretation of meanings could be noted.

In listening, relistening, and making verbatim transcripts of interviews *and* group and ISMs, this initial step goes beyond typical phenomenographic analysis, which privileges participant utterances from interviews while using other data sources as ways to provide contextual detail (e.g., Tan & Nashon, 2013; Tan & Caleon, 2022). In this analysis, though utterances for analysis were mainly drawn from interviews, participant utterances during the Learning study discourse itself also contributed to the construction of the categories of description. This deviates from standard phenomenographic practice and represents how I borrowed phenomenographic perspectives in data analysis. Nonetheless, the inclusion of Learning study discourse utterances maintains many of phenomenography's underpinnings as described in Section 3.1, including a focus on participants' descriptions of their experiences and the seeking of variation in those experiences through conversation (Yu, 2019). In my view, this enriches the pool of meanings while providing further avenues for triangulation and contextual understanding. Chapter 4 shows these methodological choices in that meeting excerpts are included in the presentation of findings. In addition, select Learning study research lessons are included to provide the context of the utterances.

Once transcriptions were completed and compiled, relevant field notes and teacher artifacts were inserted and referenced using footnotes throughout the transcripts. This aided the interpretation of participants' utterances by triangulating them with other data sources. Following, a selection of utterances of interest were marked, with initial interpretations noted based on the context in which the utterance was found (Marton, 1986). For example, utterances about how the teacher participants focused on their discomfort with students engaging with ‘activism’ inside of SRSE were marked as ‘SRSE activism tension,’ distinguishing itself from other tensions, such as those perceived to be caused by the curriculum or colleagues.

With an initial idea of possible ways teachers experienced learning about and enacting SRSE, individual teacher profiles were developed through a narrative account of their experiences in the Learning study (Tan & Nashon, 2013; Tan & Caleon, 2022). The descriptions were a complete rendering of the 30 weeks of the Learning study. These profiles aimed to develop a rich and nuanced understanding of teachers’ experiences to aid with the faithful interpretation of their experiences (Bowden, 1994a, 1994b). The profiles provided a backdrop against which quotations were understood and developed my emphatic understanding of teachers’ experiences (Ashworth & Lucas, 2000). This, in turn, supported my ability to describe the phenomenon of interest from the participant’s point of view before analyzing the transcripts, as is commonly implemented as part of phenomenographic methods (Marton & Booth, 1997).

As detailed by Tan and Nashon (2013) and Tan and Caleon (2022), profile construction allows “the particularities of each teacher to be examined” (Tan & Caleon, 2022, p. 3) before categories of description capture the teachers’ views across the entire data corpus. This provides a critical examination of individual utterances such that their initial meanings are not lost when data is pooled for subsequent analysis (e.g., Säljö, 1997).

In phenomenography, participants may express different conceptions at different times and in different contexts (Marton, 1981). Within the sample, individual differences are subsumed in the data pool for analysis (Marton & Booth, 1997). After profiles were developed, the next step of analysis involved looking for similarities within and between different participant utterances. Here, attention moved from individual utterances, previously marked in the transcripts and understood considering teacher profiles and other data sources, to the meaning found in the utterances. These were compared across the entire data set. There was thus an iterative process of establishing the pool of meanings (Marton, 1986) as individual meanings were compared and noted within and between transcripts.

Searching for limited qualitatively different ways of experiencing the phenomenon of 'understanding and enacting SRSE'– recall the underpinnings described in Section 3.1.1 of the limit of human capacity to simultaneously focus on all critical features of a phenomenon (Marton & Booth, 1997) – guided the construction of the categories from the pool of meanings. To avoid research bias, my existing knowledge of 'conceptions of SRSE enactment' were bracketed when reading data pieces (Richardson, 1999) by continually asking, "what was the teachers' underlying intention" (Taylor & Booth, 2015, p. 1306). Through the iterative reading of the pool of meanings, 68 intention codes, or codes brought together based on similarity, but distinct based on differences, were constructed over a total of around 750 coded extracts. Codes were constructed by identifying recurring words, phrases, meanings, and relationships in the marked portions of the pool of meanings. Here, employing conceptual perspectives from the literature review was particularly useful (e.g., Chapter 2, 'espoused benefits to students'). They guided the coding of the pool of meanings based on the research questions.

Some of the most common codes included 'meaningful student outcomes,' 'students' skills and readiness,' 'interactions with school culture,' and 'using the 3-VSL'. Codes with similar meanings were grouped, and themes and patterns that cut across the four participants were identified and labelled as initial categories of description. Some of these initial categories included 'ways to do SRSE,' 'benefits and constraints of SRSE,' and 'descriptions of educational assumptions.' The categories were further defined and delimited by the differences in what teachers focused on in the category and the meaning they ascribed to that focus (the structural and referential aspects, respectively). For example, the influence of 3-VSL (structural aspect) varied across the initial categories, from ways to highlight potential gaps in science learning opportunities to a reflective tool used to improve practice (both referential aspects). In later categories, the purpose teachers ascribed to the use of SSIs in SRSE (structural aspect) varied across categories as well, including increasing socioscientific awareness for future independent purposes, to an invitation to action to reduce harm SSIs could cause.

The categories were checked against other data sources for accuracy and opened to scrutiny by an experienced phenomenographer (my dissertation supervisor), my dissertation committee members, and my doctoral cohort members. Once data analysis began, I had rotating, prolonged and in-depth discussions with my doctoral supervisor, committee, and members of my doctoral cohort every three to four weeks. This allowed my analysis and representation of the data to be scrutinized and biases I might bring to the research process to be highlighted. In total, the process allowed my interpretations, concepts, and ideas to be tested, which aided in developing the categories of description. This served the purposes of a confirmability and dependability audit (Guba, 1981) and also acted as peer debriefing (Boulton-Lewis et al., 2001). Categories were subsequently adjusted and readjusted until the "whole system of meaning … stabilized" (Marton, 1986, p. 42).

Finally, conceptual perspectives from the literature review were drawn on to help label the categories of description and their relationships in the outcome space. For example, Zeidler (2014) and Pedretti and Nazir's (2011) work was drawn on to help develop the category 'Promoting individual student transformations through SRSE.' This allowed the ways the teachers aimed to act on students' attitudes and beliefs to be made clear in the titling of the category. It also allowed the different ways the teachers cast the object of student transformation to be more easily identifiable and comparable between categories. Additionally, I connected the SRSE teaching experiences found in each category of description to the 3-VSL. I mapped the teachers' research lessons and related teaching experiences in Figure 3 from Section 2.4.2. Like above, this was done to explore each enactment of SRSE in relation to the STSE, Socioscientific Issue-based, STEPWISE, and Critical Pedagogy of Place frameworks reviewed in Chapter 2. This gave me additional understanding to label the categories and think through their relationships. The outcome of this analysis is presented in Figures 7, 8, and 9.

Phenomenographic perspectives of learning (as discussed in Section 3.1.1) were also incorporated to aid in ordering the categories. Namely, the categories illustrated how the teachers paid attention to more critical aspects of SRSE teaching and learning in the higher-order categories. This construction of categories is also consistent with Marton and Booth’s (1997) ordering process, where lower-ordered categories are subsumed into higher-ordered ones. The hierarchically ordered categories are thus parsimonious and show the relationships between them (Marton & Booth, 1997). In one sense, this relates to the educational utility of the categories (as described by Taylor and Booth [2015] and Miechie et al. [2019]). Teachers’ SRSE experiences can be argued to occur in more or less educationally beneficial ways (e.g., Hodson, 2011; Levinson, 2010), and utility-wise, knowing which critical aspects need to be discerned or focused upon to foster these beneficial ways would be useful for teacher educators and professional development leaders.

To organize the excerpts presented in Chapter 4, I gave them labels and timestamps. As an example: Int. 1, 12:36. This shows from which data sources and at what time the utterance occurred (Appendix A contains a chronological record of all meetings). Interviews are labelled

‘Int.’ Individual Support Meetings ‘ISM.’ And Group Meetings ‘Group.’ Numbers after the name indicate order.

3.7 Trustworthiness and Issues of Validity and Reliability

This section highlights the considerations and steps taken to ensure the trustworthiness of the research study (Lincoln & Guba, 1985). Trustworthiness typically relates to the truth value, applicability, consistency, and neutrality of the results reported and the methods used to achieve them (Guba, 1981; Lincoln & Guba, 2013). Lincoln & Guba (1985) highlight the importance of credibility (truth value), transferability (applicability), dependability (consistency), and confirmability (neutrality) as criteria with which to judge the quality of research in a naturalistic paradigm.

Phenomenographic research falls in the naturalistic paradigm. As such, phenomenographic approaches draw on and have in common ways to address trustworthiness found in other qualitative research approaches, while also having some differences owing to phenomenography's own assumptions (Åkerlind, 2012; Hajar, 2021; Marton & Booth, 1997). The terms validity and reliability draw critiques regarding their appropriateness in a naturalistic paradigm. I take guidance from Åkerlind (2012) and Sandberg (2005), who argue they still warrant attention from qualitative researchers by offering a useful heuristic for discussion, despite needing to be reframed and, in many instances, extended based on the context of the research approach. This stance is true in a phenomenographic research tradition, in which authors still tend to use terms such as validity and reliability to establish trustworthiness (e.g., Go & Pang, 2021; Hajar, 2021; Tight, 2016), likely based on phenomoenographies’ empirical roots. As will be elaborated in the following sections, various strategies were employed to work towards credibility, transferability, dependability, and confirmability in line with other phenomenographic studies, and other phenomenographic researchers have used these criteria to work toward validity and reliability (Miechie et al., 2019; Tan & Nashon, 2013; Wood, 2000).

3.7.1 Addressing Validity

Validity is regarded as the extent to which an inquiry is seen as investigating what it sets out to investigate. In phenomenographic research, this would be how well the research outcomes correspond to the experience of the phenomenon as indicated by the participants (Åkerlind, 2012). As such, the focus on validity in phenomenographic research is aimed at ensuring the methods used appropriately reflect the research aims (Ashworth & Lucas, 2000; Bowden, 1994b) and that barriers to a faithful account of participants' experiences are addressed.

The most popular way to work toward a faithful account of experience begins in the data collection phase (Entwistle, 1997). Since in phenomenographic research it is paramount that participants describe their relationship to a phenomenon without researcher interference, interviews which are open, semi-structured, and that allow interpretation on the part of the participant are employed as initial validity checks (Dawes, 2017; Taylor & Booth, 2015; Töytäri et al., 2016). This was the case in the present study, as described in Section 3.5.1.

Following these initial validity checks, phenomenographers typically seek some form of corroboration of the data either through intra-researcher and/or inter-research interpretation. Intra-researcher corroboration was primarily practiced in this study through the collection and analysis of multiple data sources (as described in Section 3.5) to show that similar findings are supported by different sources. For inter-researcher corroboration, I employed peer debriefing (e.g., Boulton-Lewis et al., 2001; Töytäri et al., 2017; Wood, 2000) in order for my growing insights to be refined (Lincoln & Guba, 1985) and to show that my interpretations were defensible (Åkerlind, 2012). This was done with an experienced phenomenograher (Section 3.6) as well as with members of my research committee.

Other strategies I used to work towards validity included prolonged engagement in the context under study (Lincoln & Guba, 1985; Taylor & Booth, 2015). I was present with the teachers, watching research lessons, or in group and individual meetings for over 30 weeks of the academic year. This works to address a critique of phenomenography by Säljö (1997) that the social context of the study can impact participants' utterances such that they may feel compelled to 'please' the researcher. My prolonged involvement with the participants enhanced their comfort with my presence and subsequent comfort in giving truthful accounts of their experiences. It also allowed me to learn about the school culture and the context of Learning study. For example, I became aware of some of the pressures the traditional science education teaching and learning culture provided participants in terms of most condoned or questioned pedagogies and assessment practices. Finally, it provided ample time for me to become aware of some a priori assumptions and to respond accordingly to avoid bias, as will be described below and in Section 3.8.

The validity checks mentioned above largely fall under Guba's (1981) credibility aspect of trustworthiness. For this aspect, the researcher should show that their interpretation of the data, among many possible legitimate interpretations, can be persuasively argued for and that the findings are, therefore, plausible. In addition to these practices, phenomenographers also frequently address validity by ensuring their own biases are checked and interrogated (Ashworth & Lucas, 2000; Tan & Nashon, 2013). Like the aforementioned strategies I have employed, this seeks to ensure research findings adequality reflect the phenomenon studied by constantly testing researcher predilections as strenuously as possible (Guba, 1981). The idea here is that since the researcher is the instrument of data collection in phenomenographic studies, their own assumptions need to be taken into consideration to help ensure findings are credible. In this way, there is a direct relationship between Guba's (1981) credibility and confirmability criteria.

In the present study, biased data was initially accounted for by starting thorough data analyses after the study was completed (Tan & Nashon, 2013). This practice followed Sandberg's (2005) guidance, aiming to avoid premature interpretations that might bias analysis. 'Bracketing' was also employed to avoid researcher bias. Here, I aimed to withhold my own theories and prejudices as much as possible when interpreting the participants' lived experiences (Guba, 1981). Peer debriefing was also employed to avoid researcher bias (Boulton-Lewis et al., 2001). During the process of peer debriefing, instances were raised in which my own predilections seemed to have influenced analysis or the construction of categories. This prompted subsequent reflection and further analytic refinement. These practices aimed to ensure that the research outcomes were dependent upon what the teachers said/did and not what I assumed or brought with me to the analytic process (Ashworth & Lucas, 2000).

Chiefly, I followed steps as indicated by Sandberg (2005) to "bracket knowledge which is relevant to the issue at hand" (Giorgi, 1990, p. 71). These included:

1. Orienting myself to how the research object appears throughout the process so as to be open to possible variations and complexities in how teachers were experiencing learning about and enacting SRSE.
2. Orienting myself to describing the experience under investigation and not explaining why it was so, as to keep the focus on the participants' experience.
3. Treating all experiences as initially equally important to avoid value judgements which may turn attention away from truthful interpretations and potentially advocate for my

own preferences. In other words, avoiding a universal judgement of which ways to enact and understand SRSE were ‘best’ or avoiding judgement of teachers’ experiences against the 3-VSL and what I interpret each Vision to privilege.

4. Adopting different interpretations than the first tentative interpretations of individuals' experiences and maintaining that diversity until the basic structural features and/or meanings of experience stabilized. In other words, entertaining multiple categories of description (as described in Section 3.6.1) to avoid a premature arrival of ‘final’ categories of description (Ashworth. Lucas, 2000). This process was greatly aided by peer debriefing, as described above.

Another strategy taken to account for bias included practicing reflexivity. Here, I intentionally expressed my underlying assumptions, which could cause me to formulate questions and present findings in particular ways (e.g., Section 3.8), acknowledging my background and agenda for the research study. This allowed me to position my background and agenda in ways that could complement my dual roles as facilitator and researcher, honouring the insider and outside knowledge I bring to the research (this point will be elaborated on in Section 3.8). Following the recommendations of Guba (1981) and Lincoln and Guba (2013), a researcher’s journal was used to practice reflexivity in situ and aid in bracketing. Before each contact with participants, I wrote a small paragraph detailing some of my hopes and ideals for the session. These made clear to me some underlying assumptions, allowing me to critically examine my roles and avoid overly influencing the participants or data. For example, in knowing my hopes for the session, I could more accurately attempt to bracket them, remaining open to the teachers’ interests and experiences.

The final strategy taken to guard against bias was the construction of individual participant profiles (section 3.6.1). This aided me in building an empathetic understanding of the participants, dwelling on their lived experiences versus mine. Ashworth and Lucas (2000) note that this procedure compliments bracketing as an approach to faithfully enter another's lifeworld. The profiles likewise served as a source of rich descriptions of the research context.

Rich descriptors of context lead to the third criterion proposed by Lincoln and Guba (1985) to judge the quality of qualitative research, and, as argued by Åkerlind (2012), falls within the validity sphere of trustworthiness. Transferability (Lincoln & Guba, 1985) speaks to the criteria that research results should have some use in different contexts, able to be applied as 'working hypotheses' tested elsewhere. Recently, Yin (2014) has defined this quality as contributing to analytic generalizability, which involves "a carefully posed theoretical proposition …[that] can take the form of a lesson learned, working hypothesis, or other principle that is believed to be applicable to other situations" (p. 68). In this regard, results can be transferred to select contexts, rather than generalized to all. In phenomenography, transferability is most often addressed by providing thorough descriptions of the context of research so that the degree of similarity (or fittingness) between contexts can be ascertained (e.g., Tan & Nashon, 2013). This was addressed in the present study through the construction of participant profiles but also through the detailed rendering of the entire Learning study (Appendix B).

3.7.2 Addressing Reliability

Reliability in a naturalistic research paradigm relates to the methodological procedures which work towards ensuring consistency in data interpretations (Åkerlind, 2012). The analogous term by Lincoln and Guba (1985) and Guba (1981) is dependability. They point out that this aspect of trustworthiness embraces the need for quality qualitative research to show how findings and interpretations could be determined to be an outcome of consistent and dependable processes. In phenomenographic research, elements of dependability are often referred to as reliability (Åkerlind, 2012; Taylor & Booth, 2015; Wood, 2000) and are typically addressed by what Åkerlind (2012) calls dialogic reliability checks and coder reliability checks.

Dialogic reliability checks refer to the agreement researchers seek in research outcomes through discussion and critique of data and interpretive hypotheses. This check typically involves a detailed account of interpretive steps that track any changes in insights (e.g., Åkerlind, 2004; Taylor & Booth, 2015; Wood, 2000) as well as illuminative discussions where analyses can be tested and scrutinized by others (Bowden, 1994b; Tan & Nashon, 2013; Töytäri et al., 2016). This was practiced extensively in this research study, typically alongside peer debriefing. When analysis began, I would meet with at least one of my research committee members every two to three weeks to engage in dialogic reliability checks. I would describe in detail the processes by which I drew inferences from my data to construct categories and develop codes, highlighting portions of my researcher's journal or other data sources as evidence. Following the recommendation of Marton (1986), the purpose of these meetings was not to see if others could independently produce my findings. Rather, reliability was instead judged based on whether a category could be found by others once it is described to them by the original researcher.

Coder reliability checks occur when two researchers independently code data and compare results. This practice is typically termed 'interjudge reliability' (Cope, 2004) in phenomenographic research and is widely practiced (Boulton-Lewis et al., 2001; Han & Ellis, 2019; Sandberg, 1997; Tight, 2016; Walsh et al., 1993). Some studies report on percentage agreement between phenomenographers when researchers independently classify interview transcripts against previously made categories of description (e.g., Cope, 2004; Säljö, 1988).

Coder reliability did not occur in the present study. Instead, 'interjudge communicability' was employed as a measure of reliability (Cope, 2002) during meetings where dialogic reliability checks and peer debriefing were also practiced.

Interjudge communicability follows the recommendations of Säljö (1988), who notes that reliability in phenomenographic research should measure "the communicability of categories and thus gives the researcher information that someone else can see the same differences in the material as he or she has done" (p. 45). This builds from the critiques of interjudge reliability in phenomenography levelled by Sandberg (1997), including the recognition that interjudge reliability borrows from an objectivist epistemology. As described in Section 3.1.1, phenomenography assumes that knowledge exists, and therefore emerges, in the relationship between an individual and the world. As such, categories of description do not represent an aspect of objective reality. They are a researcher's analysis of variation in a group of individuals' utterances about their *experiences* with an aspect of reality. As Sandberg (1997) argued, interjudge reliability is unsuitable as a reliability measure in phenomenographic research.

Nonetheless, like dialogic reliability, interjudge *communicability* upholds Marton's (1986) assertion that the categories of description come about as a form of discovery and "discoveries do not have to be replicable" (p. 35). In the same way one would not judge the classification of two species based on if two researchers could independently produce them, categories of description should instead be judged based on whether a category can be found by others once it is described to them by the original researcher.

The final reliability check used relates to the bracketing of prior knowledge and what Sandberg (2005) describes as interpretive awareness. In this sense, to make consistent, dependable interpretations of research, one's preconceptions must be acknowledged, and changes in insights tracked. To "deal with our own subjectivity throughout the research process instead of overlooking it" (p. 59) becomes a way to work towards reliable results (e.g., Taylor & Booth, 2015; Wood, 2000). Dealing with my subjectivity is shown in Section 3.8 through my positionality writing. Interpretive awareness was also practiced in my pre-session reflective entries and by looking back on them throughout data analysis.

The final two strategies employed to address credibility included member checking and triangulation. In member checking, "data, analytic categories, interpretations, and conclusions are tested with members of those stakeholding groups from whom the data were originally collected" (Lincoln & Guba, 1985, p. 314). From June to December 2021, the first and second interview transcripts were distributed to the interviewees, and a verbal summary of key points was provided as the participants and I continued to plan to disseminate some of the learnings of the Learning study. I asked each participant to confirm that their thoughts and experiences were correctly captured and to correspond with me over several weeks if any changes should be made. No interviewees requested any changes.

In some naturalistic research, member checks also include the final outcome of the research (Lincoln & Guba, 2013). This was not practiced in this study owing to the pooled nature of phenomenographic results. In other words, since the categories of description are a "researcher's analysis of variation *in a group* of individuals' statements about their experiences of an aspect of reality" (Cope, 2004, p. 10, italics added), individual participants are likely unaware of others' conceptions. Member checking full categories of description would therefore be unhelpful as a credibility technique. However, the overall findings of the entire study will be made available to the participants via future published journal papers, and a presentation will be implemented as part of the dissemination practices noted in the application for ethics approval for the study. During the presentation, the participants will be explained as to the analytic process and told that the categories are not representative of individuals within the study.

Multiple sources of data, as described in Section 3.5, were used as sources of triangulation in the present study (Guba, 1981; Lincoln & Guba, 2013; Mathison, 1988). Relying on multiple data sources addresses bias issues (Guba, 1981). It also works to exploit different yet complimentary data of the same phenomenon to address validity concerns and strengthens transferability claims when done with participant profiles. For this Learning study, triangulation was particularly powerful as I was able to collect multiple data sources throughout the process, as is common in other Learning studies, including reflective journals (Tan & Nashon, 2013), field notes (Miechie, et al., 2019), and observations (Pang, 2006). These multiple sources showed that similar findings were supported by different sources or allowed me to further my analysis when inconsistent or contradictory findings became apparent (Mathison, 1988).

3.7.3 Summary

In a naturalistic paradigm, issues of validity, reliability, and trustworthiness are a natural state of things. They are not to be guarded completely but are considered part of the "real world" (Guba, 1981, p. 88). As such, while bracketing, reflexivity, triangulation, and various forms of peer debriefing work to address some of these issues, my practices are not unassailable from critique. Their employment merely increases the probability of my study's trustworthiness and represents my attempts to persuade others of the trustworthiness of the results. As was explained, a crucial piece of research in a naturalistic paradigm is for the researcher to make their biases known so they can be dealt with. Section 3.8 presents my work in this area.

3.8 Self in the Study

Much discussion of researchers' status as an 'insider' or 'outsider' in qualitative research generally (Dwyer & Buckle, 2009; Kerstetter, 2012; Merriam et al., 2001), and educational research specifically (Coghlan & Shani, 2005; Greenwood & Levin, 1998; Pedretti, 1996; Tan, 2014b), have been forwarded. Dwyer & Buckle (2009) have argued that there are very few cases in which a researcher can be a complete insider or outsider: in most situations, researcher identities are relative to the context of the research. As such, most researchers fall somewhere in 'the space between' these identities and thus "assume a responsibility to understand where they are positioned within this space to explore how their status may affect the research process and its outcomes" (Kerstetter, 2012, p. 101). To articulate how my status affects my research process and outcomes, I draw on the between space to highlight what resources and insights I bring to participants as an 'outsider' (Greenwood & Levin, 1998; Tan, 2014b), wearing my 'researcher-facilitator hat', as well as what knowledge and experience I have that might aid my role as facilitator 'inside' the study (Pedretti, 1996), donning my 'facilitator-researcher hat'. My agendas, interests, biases, and experiences inevitably reflect the priorities, values, and judgements of my insider-outsider roles, necessitating the need to make them known (Åkerlind, 2012; Merriam et al., 2001).

3.8.1 My Experience with Science Education and Social Responsibility

The science classroom, like for so many students, was my solace. I found the wonder and curiosity of exploration a comfort from my childhood real-world of bullying and prejudices. Despite my growing affinity for science, some instances in my science education gave me pause. A Grade 12 Biology teacher commented that homosexual organisms should not exist. Another science teacher laughed at knowledge systems differing from scientific dogma. Another relegated Indigenous, racialized, and marginalized scientists to a single “Diversity Day” after term exams. What was going on here? Why did we promote queer pride and visibility through a 'gay-straight alliance’ (as it was called then), yet in the classroom context, contradict that message? Why did we have an ‘everyone can be a scientist’ poster hung on the bulletin board, but only showcase ‘scientist’ in the narrowest of demographic terms? Why did we celebrate the diversity of human thought in the humanities wing of the school, but brush off that thought as ‘trivial’ in the science wing? It was in these moments I recognized the comfort and safety I craved in science class was not available to all students, and that science class even propagated some of the prejudice I initially fled. It was in these instances I knew I wanted to make change.

When I became a science teacher, the interaction between teaching for equity, social justice, and regeneration became my focus. I thought science class should be a safe, welcoming space for all, where students and teachers could discuss science’s racist, colonial, and heteronormative past in the quest for reconciliation (Fuchs, 2016). I also recognized the power of scientific studies in bringing increased awareness and potential solutions to some of humanity's direst problems. Science was (and still is) a body of knowledge, procedures, and ways of knowing that amount to a lot of power in the world. My science classes would not deny students that power, yet they would not claim that was the only power worth wielding (Fuchs, 2019).

This stance was easier envisioned than practiced. As I tried to meld various purposes for science education (McKernan, 2008), I was often confronted by the operational ideologies of my school (Eisner, 2002). This ideology, based on what was *actually* happening in my school system, left little room for critical thought about how to approach the science curriculum.

Ensuring the operational ideology of my school was promoted within the classroom took time. That time taken was time taken away from thinking and implementing an approach to science education that was true to my values and resonated with why I initially joined the profession. As a result, I was often led to teach in much of the same ways I had been taught science (Evagorou & Puig Mauriz, 2017; Sadler et al., 2006). I focused on the small bullet points of the science curriculum, told students they needed to know content to progress to the next educational step, and ignored student interests, histories, and values lest it took time away from what the Ministry of Education felt important. Increasingly, I began to lump dominant science education practices together under one large idea of 'bad' teaching.

It was in this environment, as a teacher, I understood how hard it was to teach in line with my values and beliefs while still being true to my professional duties. This understanding underscores my initial pursuit of a science education steeped in inclusion, action, and social responsibility, as well as my recognition of the challenges it takes to pursue this with students in various school climates. Both facets enable me to empathize with the teachers participating in my study, shaping my insider knowledge.

3.8.2 My Experience with Professional Development and Theoretical Frameworks

As a teacher pulled by my moral compass and professional obligations, I began to lean on colleagues to offload the constraints already mentioned to develop my practice. I was heavily influenced by my magistral and first-year teaching experiences, where various iterations of collaborative teacher inquiry were the preferred method of PD. These experiences led me to develop and lead such groups in various schools and district associations, with associated knowledge dissemination endeavours (Fuchs & Arsenault, 2017; Fuchs & Arsenault, 2018; Fuchs, 2018; Fuchs et al., 2021). Importantly, being part of these groups gave me insights into what I felt makes them most powerful.

First, some actant was needed to scaffold and push teacher learning in directions the teachers deemed valuable. Whether a note-taker, room-booker or general facilitator, most educators were too busy during a school day to consistently take on these essential roles. Second, collaboration, especially when faced with a restrictive operational ideology or school culture, was required. Collaborative peers provided educators with like-minded colleagues and benevolent antagonists in which spaces to confide and pursue shared goals could be developed. Third, theoretical perspectives open a myriad of possibilities for pedagogical exploration. In one group I was part of, we pursued the 'co-existence claim' (Babai & Amsterdamer, 2008; Potvin et al., 2015; Shtulman & Valcarcel, 2012), which postulates a plurality of concepts always exist at one time in an individual and these concepts can therefore compete (Potvin, 2017). Approaching instruction with the idea that student conceptions *cannot* be changed, instead they always 'co-exist', foregrounds that students must be guided to understand in which context certain conceptions should be used. This resulted in a substantial change in our group's classroom practice (Fuchs et al., 2021).

From these experiences, I bring insider knowledge of teacher collaborative learning groups to the present study. However, it was largely due to these experiences that I was led to pursue Learning study in my doctoral work, as it championed aspects of PD mentioned above (Ko, 2019). Exploring Learning study literature also made salient the multitude of pathways or networks which drive teacher change (as discussed in Section 2.4). There are interconnections and complexity between teachers' knowledge and beliefs, outcomes of experimentation, and participation in collaborative communities (e.g., Attorps & Kellner, 2017; Clarke & Hollingsworth, 2002; Howell & Saye, 2016; Lewis, 2009; Lewis et al., 2019; Morris & Hiebert, 2011; Nilsson & Vikström, 2015; Tan & Nashon, 2013). These works shaped my belief that participation in a Learning study could provide a myriad of experiences to develop teachers' practice and explore novel approaches to teaching and learning. My understanding of Learning study and experiences with it in graduate work, enable me to contribute this outsider knowledge to my study.

3.8.3 My Experience with Different Purposes of School Science

The first unsettling teaching observation I had was in my second year of teaching. It was an AP Biology class, and I had been trying a 'flipped classroom' approach (Herreid & Schiller, 2013). There, students would watch videos on the concepts of a lesson and come to class to engage in activities that would deepen understanding. Following my values for science education, these activities were related to students' lives and their interests, had elements tied to community problems that required ethical and moral reasoning, and the products of the activities could be used to promote social change. However, following the class, I was called to the principal's office – still unsettling regardless of one's position in a school – and I was told the observation had gone poorly. The reasoning was that for most students, their notebooks – showing the efficacy of my approach – were wanting. There were few notes, little questions, absent titles, and for some, a completely blank series of pages.

Upon reflection, I realized that in the pursuit of my values for science education, I had forgotten the building blocks of the discipline. In truth, I regarded the content and concepts of AP Biology as far easier, and far less important, than I should have – reflecting my earlier admission that those aspects were part of 'bad' teaching. In my pursuit of an accessible, relevant, and transformative science education, I ignored the importance of foundational content and concepts all students needed to allow them to build more complex understandings.

Overall, this experience reframed some of my conceptions of science teaching and learning. On one hand, the science curriculum I experienced through high school and undergraduate was taught as an intellectual pursuit, a means to enter and contribute to the Canadian economy, and with little care for who was accepted or denied entry into the scientific discipline. During my master's degree and first experiences with teaching, however, I viewed the science curriculum as one to bring about social change and provide students with powers that could allow them to make conscious choices. Naively, I pitted these purposes of science education against each other, as illustrated in the vignette above, hoping I could find *one* that would stay true to my goals. However, as Nodding (2004) points out, for a subject to be a part of education it needs to be "laid out against the whole continuum of human experience" (p. 169). To truly capture the whole continuum, many purposes of science education need be at play. Student history, interests, and morals should be promoted in science class; students should be able to see how science can be a vehicle for social change and disrupt the status quo. Also, students that wish to become scientists and love the content and concepts ought to be supported as well, no matter my previous experiences with this approach to science education.

In relation to the present study, this framing of science education led to multiple outcomes. Chiefly, it informs a 'letting go' of my SRSE agenda in the present study with teachers. SRSE is an approach to science education I am interested in understanding in diverse practice situations. Certainly, it has a broad agenda, as described, leaning toward Vision III, but it also recognizes the necessity of the other Visions and the plurality of goals inside of Vision III. How each Vision supports SRSE, or more accurately, how different teachers draw on each Vision to support SRSE – and in which context, for what issue, and through what means – is still unclear. As such, I am not interested in propagating what it should be, but rather, what it could produce. As described above with my unfavourable teaching observation, the narrow view of what should be versus what could be produces blind spots and hindrances to student learning.

My ideas are not a panacea to science education issues, and I need to work alongside the teachers in my study to develop shared and better understandings.

Second, appreciating the multitude of purposes for science education allowed me to relate my insider-facilitator knowledge and outsider-research knowledge in a dialectic (Pedretti, 1996), wherein roles are aimed at mutual support to inform and complement each other. One example comes from the ISMs described above. Sometimes, the teacher required direct support from me as a facilitator, which necessarily impacted my role as a researcher. This back-and-forth-ness between being a researcher and facilitator reminded me of Wong's (1995) descriptions of privileging 'researcher' or 'teacher lenses.' In my research journal, these were termed as 'researcher hat' or 'facilitator hat,' and I took care to find instances, as suggested by Wong (1995), and in a similar sense Pedretti (1996), where the hats could "productively coexist" (Wong, 1995, p. 27). As an example, framing a question regarding the use of Hodson's (2014) different categories with which to interrogate SSIs (e.g., economic, social, etc.), I explored which categories the teachers thought most fruitful for their students and their object of learning (researcher hat) while concurrently offering different perspectives to expand the choices available to them (facilitator hat).

This relationship is also evident in my draw toward Sjöström et al. (2017) 3-VSL. It provides theoretical perspectives echoing my 'letting go' already described. Though SRSE leans towards Vision III, in employing the 3-VSL, I attempt to make clear the diversity of potential SRSE engagement teachers could have. A focus on social change can provide students and teachers alike with a motive for learning and teaching scientific concepts, while scientific concepts can provide grounding for transformative action (Allchin, 2021). In this way, the 3-VSL can encourage a 'micro-political' process among members of the Learning study (Bencze, 2020). Here, diverse perspectives and practices under the umbrella of 3-VSL can come together, be debated, and negotiated on the way to eclectic implementation. This decision-making process upholds “liberalist individual rights to self-determine perspectives and practices” (Bencze, 2020, p. 745), which Bencze (2020) argues should be maintained in educational contexts seeking action and activism through science and technology education. The theory employed thus aims to bolster the co-constructed nature and democratic processes of the Learning study under the broader and shared goal of SRSE.

What was forwarded in this section was how my study was shaped by prior experiences encountering a plurality of science education practices and teacher professional development endeavours. As a result of these understandings, I’m provided with salient reminders of where between my insider-outsider identities I inhabit and how each identity informs and can strengthen the other. These, in turn, aided in the bracketing-reflexivity process employed throughout my study and during data analysis, as described earlier in Section 3.7.

Chapter 4. Results

How the heck do you try to create an issues-based, scientifically rich conversation that leads students to care enough to act? – Mike

SRSE doesn't have to be like full-on huge action. But it's a spectrum or continuum like everything else, and all movement towards it, wherever that looks like, whether it's a ten-minute conversation or a month-long project, is good for students – Nicole

In this chapter, I answer the research question: **How did high school science teachers participating in a 3-VSL-framed Learning study understand and enact SRSE?** I also answer the following guiding questions:

(1) What different approaches did participating teachers develop to teach socioscientific issues in their classroom settings?

(2) What were the perceived challenges participating teachers faced while teaching socioscientific issue-based lessons?

(3) What strategies did the participating teachers develop to tackle challenges faced in teaching socioscientific issues?

Borrowing phenomenographic perspectives, three categories of description are used to answer these question. I labelled each category an 'approach' to SRSE. They include: (1) Developing a balanced stance to new socioscientific issue-related curricular initiatives; (2) Promoting individual transformation through SRSE; (3) Promoting students' engagement with collective social action.

Within each category, teachers focused on three central aspects of learning about SRSE through the Learning study discourse, which explain each category. I labelled these aspects as: students' level of participation, objects of student development, and orientation to SSI engagement. The first and second explanatory dimensions represent how teachers thought about students' level of involvement with SSIs and what object they deemed essential to act upon to engage students. These explanatory dimensions directly relate to how SRSE is understood and enacted by the teachers within each approach (or category of description), representing the central research question and the first guiding question. The third explanatory dimension represents how the teachers oriented themselves to address each SRSE approach's challenges. This explanatory dimension directly relates to second and third guiding questions. The challenges and strategies contain pedagogical insights and personal reflections. Pedagogical insights are practice-focused ideas concerning teachers' day-to-day, such as requisite knowledge, skill, and experience. Personal reflections encompass the teachers' beliefs, leanings, and educative ideals. Iterations of Table 7 are used throughout this chapter to guide and summarize the salient points from the analysis.

Table 7

Categories of description summarizing key points in Chapter 4.

Research Questions	Explanatory Dimensions	Categories of Description 'Approaches to SRSE'		
		1. Developing a balanced stance to new socioscientific issue-related curricular initiatives	2. Promoting individual transformations through SRSE	3. Promoting students' engagement with collective social actions
How SRSE was understood and enacted	Students' level of participation	Students' level of involvement with SSIs		
	Object for student development	Object deemed essential to act upon to engage students		
Challenges arose and strategies developed	Orientation to socioscientific issue engagement	Pedagogical insights and personal reflections to address SRSE challenges		

Within each section, excerpts from the three participants who taught research lessons are presented, along with descriptions of other teaching experiences most representative of each category. In the remainder of the dissertation, I will refer to specific excerpts and therefore they are individually numbered. Excerpts I feel give context to the central analysis are not numbered and appear in the body of this chapter. To provide greater context to aid in interpreting the teachers' excerpts, select research lessons are also described to illustrate key ideas running through each category. This reflects the pooled nature of the phenomenographic analysis employed (Marton & Booth, 1997). Faye did not teach any research lessons. However, the description of her individual experience was used in constructing the categories.

4.1 Approach #1: Developing a Balanced Stance to New Socioscientific Issue-Related Curricular Initiatives

In the first category of description, or approach to SRSE, the teachers' viewed SRSE as developing a balanced stance to new SSI-related curricular initiatives. They sought to leverage all three Visions of scientific literacy – conceptual, contextual, and critical – to develop in students a critical lens toward SSIs based on a strong understanding of scientific concepts and processes. This focus was a direct response to the revised curricula focusing on developing students' ability to bring scientific perspectives to bear on "social, moral, and ethical decisions and actions in their own lives, culture, and the environment" (BCME, 2018).

The importance of scientific backing (i.e., knowledge of scientific content and processes) to bring scientific perspectives to bear was central to the teachers. On the one hand, it was seen as the hallmark of science education. For example:

(1) Mike: I think [SRSE] starts for me with the conceptual. So, we are still creating informed professionals. You know, I want my doctors to have a command of physiology. It's not like that can start in university. We need to be building that now. (Int 2, 23:38)

On the other hand, it was seen as a necessary building block to aid students in being critical of SSIs. As Dave and Nicole note:

(2) **Dave:** You need to live in the conceptual-contextual enough to really get [students] to work with that critical. Because you can jump right to the critical and they're like, they didn't have, they didn't see that contextual video for an hour on pollution in certain communities. Right? So, the critical would lack substance. (Int 2, 1:48:41)

(3) **Nicole:** They really can't justify the science [of COVID-19 control measures]. That has to be a focus. It's pretty surface. Like, why do these pandemic measures work based on the science? And so part of me is like, oh, this could be so much juicer, but like actually this is a step we need to get to the juicy contextual and critical stuff based on their survey responses. (ISM 2, 1:11:52)

In these examples, Dave comments on the need for scientific backing, in general, to be critical of any SSI, and Nicole provides a concrete example from her research lessons. Nicole felt her students needed a robust conceptual base to pursue the 'juicer' contextual and critical areas related to pandemic control measures. From this conceptual backing, the teachers' viewed this approach to SRSE as preparing students to be *engaged critics* of SSIs under the moniker 'informed citizens.' This is students' level of participation with SSIs (Table 8, row 3). Nicole, Dave, and Mike explained this view in Group Meeting 2:

(4) **Nicole:** I think SRSE is about pairing students with the understanding of science and an issue so they can make informed decisions in their life. Can you create citizens after school that even if they're not scientists, know how to filter through what's important

based on scientific research and not only feelings or fake news or whatever? (Group 2, 6:46)

(5) Dave: Like I want, if we want to be socially responsible, we got, we got to make kids informed citizens. Really able to dive into those issues, you know? (Group 2, 1:04:45)

(6) Mike: We're not here to influence the students' decision with SRSE. We're going to ask them what questions they would land with if a Minister of the Environment walks in a room or if the owner of the tanker company walks in the room or the First Nations Elder walks in the room. It's about living the question; I think is more important than coming up with what to do. (Group 2, 1:01:24)

From these excerpts, Nicole, Dave, and Mike demonstrate the larger intentions of the three teachers to equip students with the knowledge and skills for future decision-making. In these quotes, the teachers were focused on preparing students to know where and how to find multi-perspective information on complex issues and fostering their ability to derive critical questions about those issues. These, in turn, were argued to bolster students continued critical engagement.

In preparing students to be engaged critics of SSIs, Dave, Nicole, and Mike focused on developing students' *conceptual and cognitive* thought space. This is the object the teachers deemed essential to act upon to engage students (Table 8, row 4). To do so, the three teachers followed similar progressions, including having students learn the concepts behind, context around, and harm caused by select SSIs. They felt students required knowledge and skills to be engaged critics. Additionally, in planning to enact, enacting, and watching their colleagues enact this approach, the teachers developed pedagogical insights and personal reflections, facilitating their continued engagement with this approach to SRSE. These insights and reflections contribute to the robustness of this category and its active description: *Developing* a balanced stance to new socioscientific issue-related curricular initiatives. Further, it highlights important setbacks and breakthroughs that were part of this process.

The analysis of the teachers' utterances revealed that the teachers perceived these insights and reflections as primarily within their locus of classroom control (e.g., how to expand their own SSI-specific content knowledge – the focus here on 'their own'). As such, the teachers' orientation to SSI engagement in this approach was labelled '*builder*,' found in the last row of Table 8. In being perceived as within their locus of control, it can be interpreted that the teachers were building on their knowledge and experience to develop a balanced stance to new SSI-related curricular initiatives.

Table 8

Explanatory dimensions for the first category of description.

Explanatory Dimensions	Category of Description 'Approach to SRSE'
	1. Developing a balanced stance to new socioscientific issue-related curricular initiatives
Students' level of participation	Engaged critics
Object for student development	Cognitive and conceptual
Orientation to socioscientific issue engagement	Builder

In the following sub-sections, I provide evidence for each explanatory dimension found in Table 8, which is then summarized in Table 9. I begin by detailing the teaching experiences most representative of the category, highlighting the first two explanatory dimensions. This is followed by central challenges the teachers identified and addressed, showing the final explanatory dimension. The order in which I present the teaching experiences and challenges identified and addressed is for ease of presentation. For example, portions of Nicole's research lessons and Mike's 'bird strike' vignette are paired with the challenge of perceived lack of knowledge because Nicole and Mike's teaching experiences more easily exemplify that challenge. However, each challenge in each category cuts across each category-specific teaching experience (i.e., in this category, each shows the teachers' orientation to SSI engagement as 'builder').

4.1.1. Nicole's Research Lessons, a 'Bird Strike,' and Addressing a Perceived Lack of Knowledge

Nicole taught her research lessons first. The lesson most representative of the balanced approach was her first in a three-series set. Nicole's object of learning was developing students' ability to propose and evaluate local and global level actions to reduce harm from pandemics based on scientific theory.

The lesson began with Nicole presenting some of the mechanisms of viral transmissions, such as the effect of droplet size, using infographics and direct instruction. Next, she provided students with various resources explaining the science behind how select pandemic control measures work (e.g., a video on how soap affects viral membranes and a website on how the R_o is reduced with social distancing). These two lesson foci were necessary given the need to build students' foundation in understanding scientific concepts, as explained above.

In teams of three or four, Nicole then had the students summarize the given resources and reflect on the control measures used in their local context of Western Canada. The students prepared informal presentations and shared them with the class. To close, Nicole gave students time to read and comment on one of the four articles they also had to read as homework. The articles detailed various environmental, economic, and social impacts of COVID-19. Nicole chose them to highlight some of the potential harms COVID-19 restrictions were having. When the articles were coupled with the conceptual backing of why the control measures were needed, Nicole intended this activity to enable her students to make thoughtful comments about some of the trade-offs of these measures. As Nicole explains: "I'm not well read, but there are actually some positives to some [control measures]. I mean there's way less CO_2 being emitted now" (ISM 3, 41:19). At the start of the next lesson, these harms and some of the trade-offs were to be shared and discussed as a class.

A pedagogical insight Nicole expressed after this research lesson, and shared by the teachers across the data pool, was the need for knowledge of the concepts, context, and harm caused by select SSIs. As Nicole explained:

(7) Nicole: I've spent the entire weekend reading about COVID, finding articles, and making them appropriate. That's a lot to do, to find out about (ISM 3, 15:20)

In this excerpt, Nicole highlights the amount of information she had to understand to choose practical and desirable articles that would support her students' in discussing some of the trade-offs of various pandemic control measures. The teachers deemed this knowledge important to scaffold student learning and a challenging area due to its potential breadth and depth. Mike brings up the content knowledge required to engage students with SSIs from conceptual, contextual, and critical perspectives in the first interview.

(8) Mike: So, how do you deal with complex issues, let alone controversial issues? It's too big, it's too big. Sort of like my understanding of Middle East politics. There's so much history and there's so much longer-term history and so many names. I can't make sense of this. So that's a powerful and humbling parallel because you realize, yeah, I too have my areas in life I am pretty darn ignorant. (Int 1, 51:32)

This comment exemplifies the teachers' recognition of the amount of information needed to move forward with this approach to SRSE. However, they also appreciated how this knowledge was necessary to engage students in ways they had not previously encountered. Thus, while this challenge was undoubtedly real, it took on a positive framing given the potential for student learning. As an example, upon teaching one of his research lessons, Dave noted the preparation required was "A lot"; however, it was also "interesting in a beautiful, stressful kind of way" (ISM 11, 2:06). Mike commented, "The reality of teaching like this is the preparation. But showing the kids you'll do it usually shows they can do it, too" (Group 7, 45:18).

The pedagogical insight of the need for knowledge of the concepts, context, and harm caused by select SSIs is also expressed in one of Mike's balanced SRSE approach experiences on 'bird strikes.' A bird strike is when a bird hits a reflective surface, typically caused by skyscrapers in metropolitan areas. In this example, Mike demonstrates the knowledge he had to flexibly leverage all three Visions in a classroom example.

(9) Mike: So basically, the context, like I brought up the context of a bird strike. They didn't know anything about it. And so, I could go into the conceptual real easily. And then I know from the conceptual I can go to the critical, to get some profound questioning around how many birds die in cities like this. Like I can read the room. From the contextual, I could have gone to the critical, too. I know about bird strikes. And so probably, I was like OK, let's go to the conceptual because generally speaking it takes so much preparation work and thinking to get them to move to a critical and that's not, we've got a short amount of time for this example. (Int 2, 1:22:08)

Mike's comfort moving into any of the 3-VSL around the issue of bird strikes alludes to his employment of the pedagogical insight described above. Mike was prepared to leverage each Vision, and his knowledge of them, to support his student's critical engagement with the topic.

This is also an example of a teacher drawing from the theoretical perspectives explored in the Learning study to articulate and understand some of their pedagogical decisions. In the excerpt, Mike describes his considerations in moving to a critical or conceptual area from his initial contextual basis. Later in the Learning study, Nicole describes a similar approach. She relays how she also leveraged the theoretical perspectives explored as a guide to structure lessons where she focuses on all three Visions of scientific literacy and decides where more information might be needed. Nicole explains:

(10) Nicole: I think the lenses were a useful tool to reflect on my own practice and what I'm trying to get my students to learn. So I think thinking about that continuum within my teaching makes you think, oh, am I doing contextual? Is it enough? Could I do it better? Oh, how could I or where could I do critical? Could I do it better? What more should I add? Is there enough conceptual? So I think in turn, by me reflecting on that more I'm reflecting on my practice more and developing my students learning. And that was one of my big take homes is just the lenses as a tool to reflect on my practice. (Group 10, 4:52)

In this excerpt, Nicole talks about how the 3-VSL 'lenses' provide her insights on which knowledge domains need greater attention in her practice, which in turn prompts her to reflect on her practice more, and by extension, better her student's learning.

While leveraging the 3-VSL is one strategy to think about all the knowledge domains in a balanced SRSE approach, Mike forwards another. In the final interview, he shares a disposition to the 3-VSL knowledge domains cultivated in the Learning study that he feels made their exploration easier. Mike continues:

(11) Mike: I have a certain confidence to be fine with the uncertainty, but most don't. We have to be, I guess, curious to lean into what you don't know with students, or where this is going to go, or we don't know where it's going to end. And I think that's initially freaky and can be for a lot of people. I think that's actually going to affect, you know, will SRSE gain a foothold as a dominant way to think about education? Well, it depends if the practitioner can embrace uncertainty. (Int 2, 37:57)

In this excerpt, Mike highlights the comfort with uncertainty that SSI-based teaching requires. As Mike notes, leaning into that uncertainty allows for more accessible exploration of diverse knowledge domains because teachers can do so in partnership with their students. At the end of the Learning study, the group reflected on the need to lean into these areas as a pathway to capture the opportunity they provided. Nicole and Dave provide examples:

(12) Nicole: I think there's a need to be OK with not knowing everything and having all the answers. Just being OK not being the expert in the room and being humble about that, I think is part of what you need to do to do this. (Group 9, 57:44)

(13) Dave: Sometimes I'm leaning into things I don't know, but creating the space for students to have the discussion, even saying, yeah, we don't know, we need to research more or maybe we can't make that statement. (Int 2, 43:07)

What Nicole and Dave described above, and Mike in Excerpt 11, is a disposition to science teaching and learning where the teacher absolves their expert and gatekeeper status. This pedagogical insight aids in exploring novel knowledge domains brought on by SSI-based instruction. In it, the teachers seek to develop a learner's disposition in self, where they inhabit and model the frame of mind often desired of students: being curious and driven, recognizing unknown areas of knowledge and experience, and approaching them ready to learn.

4.1.2 Dave and Mike's Research Lessons and Addressing 'No Values Talk'

For Dave, the balanced approach to SRSE is captured in how he described his pre-research lesson and his first two formal research lessons. Over here, the teachers' utterances, as well as a description of the pre-research lesson, are presented; the formal lessons are presented in the next section due to space constraints, a lesson of similar character labelled a 'farming practices vignette' is found in Appendix I. The vignettes are teaching experiences the teachers felt were related to the Learning study but not directly captured in research lessons or with formal observations.

In the pre-research lesson, Dave focused on the SSI of 'cancel culture' (i.e., the ostracization of individuals, ideas, and larger groups) as it relates to scientific concepts. Addressing conceptual and contextual literacy, Dave first presented key ideas about the Tragedy of the Commons and how the framework has proliferated to influence economic, environmental, and societal policy and thinking. Dave then engaged the class in checking for understanding questions, ensuring the students could demonstrate comprehension in line with the AP curriculum.

Following, Dave gave students time to read an article by Mildenberger (2019) titled *The Tragedy of the Tragedy of the Commons*. Dave chose the article to stimulate critical literacy skills. It established that a developer of the Tragedy of the Commons, Garrett Hardin, was a known "racist, eugenicist, nativist, and Islamophobe" (p. 5). Furthering critical literacy, Dave then had the class engage in open discussion around (1) cancel culture concerning scientific discovery and concepts and (2) the framing of concepts developed by 'cancelled' individuals in school curricula. Like the farming practices vignette in the Appendix I, this pre-research lesson leveraged an SSI throughout to make students more critical of cancel culture and its role in scientific discovery and communication.

For Mike, this approach to SRSE is represented by his pre-research lessons, his first research lesson, and a 'bird strike' experience (Section 4.1.1). For the research lessons, Mike's object of learning was developing students' ability to understand the why of their actions towards living a life with lower carbon emissions. He indicated that the nine pre-lessons were focused on developing students' understanding of the science behind climate change and humans' implications in its exacerbation and amelioration. As explained above, this grounding was deemed necessary for students to be critical of the issue:

(14) Mike: We did nine lessons getting the conceptual so well, I think that's the main thing. The contextual and the conceptual are doing a dance. There's a back-and-forthness, but without the critical eye. So, we're doing that dance for nine lessons. I think then you're ready to start integrating the critical lens for the remainder. (Group 9, 37:43)

In this example, Mike again draws on elements of the Learning study's theoretical perspectives to frame his pedagogical choices, talking about his pre-lessons' contextual and conceptual dance. The first research lesson then extended from this base. Mike focused on advancing and solidifying central concepts from the pre-lessons by tying them to students' perspectives. First, Mike presented his narrative for being invested in climate change, including his attendance at climate marches around the city. He followed this up by offering books, quotes, and articles highlighting different climate change lenses and invited students to comment on any material presented. In one example, students pursued the threat climate change posed and tied it to

Canada's need to transition to a 'green economy.' Mike led a discussion on factors that need to be considered should this happen, including export alternatives and the retraining of fossil fuel workers, and what other questions should be asked to get a better understanding of the trade-offs of promoting a green transition. The class closed with Mike introducing a project students would do that described a carbon emission reduction action they could take. He assigned students homework to discuss with their families which potential actions might be most appropriate.

In Dave and Mike's research lessons, there is evidence of their emphasis on developing students' cognitive and conceptual thought space, seen in their focus on students' learning the concepts behind, context around, and harm caused by various SSIs. There is also evidence of their intent for students to use this information to be engaged critics about cancel culture in scientific communication and climate change, respectively. However, important in both examples is Mike and Dave expressing their views to their students on the issues discussed (e.g., Mike's narrative for being invested in climate change). Overall, the teachers expressed concern in sharing their positions on SSIs when uncovering and evaluating the harm they can cause. The teachers believed that due to the power differential of the classroom environment, any values embedded in an SSI position would be imposed on students such that they would have no choice but to adopt them. In this approach, an important personal reflection the teachers' brought focus on is the tension between promoting SSI-specific indoctrination or providing a scaffold for future ideas.

Historically, teachers sharing values in BC was a contentious topic. Faye explains:

(15) Faye: When I graduated, and I know this is dinosaur years for many, but when I graduated, it was in 1980 from education. And in the seventies, and early eighties, you never talked about values. If you wanted to talk about values in education, you sent your kid to a faith-based school. It was not the job of a teacher to ever talk about values, and the BCTF [British Columbia Teacher Federation] even had that as a point in their professional description of practice: 'No values talk.' (Int 1, 18:45)

In this excerpt, Faye gives a historical view of how 'no values talk' was perpetuated by the British Columbia Teacher Federation in the 1980s. Picking up on this thread in Group Meeting 2, Mike and Nicole debated if students should ever hear the positions of their teachers on complex and controversial topics:

(16) Nicole: I don't think I agree with Hodson, but being neutral, like he says that's not even fair either. In that, we need to have our own opinion, but to be open to having other opinions. So, I have my opinion, but it doesn't mean that my students have to have the same opinion. But I'm going to share my opinion and we can battle it out.

Mike: Yeah, but I think there's a power differential between teachers and students that, you're right, we can share that out, and it's 'just my opinion', I'll let them know that. But there's a power differential, they are looking up to you. (Group 2, 1:02)

In this exchange, Nicole reiterates Hodson's (2014) position that teachers' being neutral on an issue is unrealistic. They should share them for students to derive their own opinions. However, Mike makes the case that teachers hold so much power in a classroom space that regardless of a teacher presenting their view, the student will have no choice but to adopt it, for example, to please the teacher. From this exchange, Faye steps back in, playing out what might happen if students are provided with no base from which to derive their own opinions:

(17) Faye: Well, I think the important point is that you as the instructor, and this is what Hodson said, you as the instructor don't stand up in front of the room and say, 'this is my belief and you need it to get an A, you all have to agree with me'. They actually talk about laying out or being open about beliefs. The kids have to start formulating an argument for why they believe what they believe. I think we all realize you can't just allow kids to decide that 'whatever I feel is right, because I feel it.' You know, you have to have a rationale. You got to have some evidence or guidance for acting and behaving in a certain way. It is light years from where education began, and that I think is the point of an educated citizen. (Group 2, 44:02)

Like Nicole, Faye deems it essential that students practice formulating and defending their views on issues. Faye feels that teachers' views are a good place to start if this is to be done in schools. That said, this debate about values and power between Mike, Nicole, and Faye is based on a choice: to present personal positions on SSIs. Dave presents a different angle to the conversation. He wonders if one can hide values by choosing not to share them or if they are always present in a teacher's actions and words. This question comes up after Mike brings up a teacher who had taken their students to a protest:

(18) Mike: A couple of years ago a teacher took their students to protest, it's at a terminus of a pipeline. And I thought you should be pulled over the coals for this. Not OK.

Dave: But didn't you go protest with some students at the climate march?

Mike: No, no. Well ... I went, and students were there. I said there's nothing to do with the school. I actually have a moral obligation to attend this rally. And I'm, I'm not supporting students. I'm not, I'm not driving students down there.

Dave: So, a moral obligation? Or is that a little bit of cognitive dissonance at play, or is that, well, protecting your job? You went. Did they see you there?

Mike: Well, I was new, my, my, third week here. They wouldn't have known me from Adam. (Group 2, 14:42)

In this exchange, Dave highlights that the mere act of Mike going to the climate march makes his values visible to students, whether he intended or not. In Group Meeting 8, after most research lessons had been taught, Dave brought up this point again. He reflects on a hike he took students on with a colleague and how that individual consistently engaged in pro-environmental behaviours as a way of being in the world. This served as a basis for discussion with students.

(19) Dave: I had this old colleague, Alex [pseudonym], and we went on a hike one day with the 'cool boys' of the school. And sometimes teaching the boys to think of, recycling as cool, is hard. But I'll never forget where we are on the trail, and Alex spent an hour-and-a-half before the hike picking up garbage. And he hadn't planned it. But that was who he was. And when we talked about it after with the boys, they appreciated that. And I guarantee you, those boys, when some of them go hike mountains, they will never leave a piece of garbage behind, and they will pick up garbage. (Group 8, 49:02)

After Dave shares the hiking story, Mike chimes in, reflecting on how his position on 'values talk' has changed since the beginning of the Learning study.

(20) Mike: It was a very, very profound time when I really started developing my lessons because it was just before, I think it was near or after Nicole's research lessons, but I just realised, right, I've actually been living a certain way for 40 years, and it's OK to share the story just as food for thought. Not as, hey, you know, you should ... not in any type of indoctrination way. And I'm super sensitive about that. But just we are living out our values. And I think that we don't have to run from that. (Group 8, 51:57)

The excerpt above shows how the teachers addressed the initial challenge of 'no values talk.' Taking Mike as a specific example, after reflection and further dialogue with the Learning study group, he framed values as consistently present in the way teachers are in schools. Mike could not 'hide' his values or 'be neutral' because his way of 'living for 40 years' demonstrated those values daily. Nicole and Dave had similar moments in the Learning study that are not captured here. From the teachers' realization that values are always present, they came to appreciate that any approaches to SRSE that leverage harms associated with SSIs require teachers' positions to be explored as jumping-off points. Otherwise, students may cultivate their teacher's unsaid but demonstrated values. Should this occur, teachers run the risk of fulfilling their earlier worries about indoctrination.

4.1.3 Category #1 Summary

In Table 9, I give examples of the explanatory dimensions for the first category of description to summarize this section. This category presents how the teachers deliberated upon and enacted SRSE focused on developing a balanced stance to new SSI-related curricular initiatives. The teachers aimed for students' participation with SSIs to be at the level of engaged critics, where they could critically question and discuss SSIs for future decision making. The teachers' felt they accomplished this by developing students cognitive and conceptual knowledge and skills related to each Vision of scientific literacy (i.e., the concepts behind [Vision I], context around [Vision II], and harm caused [Vision III] by SSI). They drew from research lessons, theoretical perspectives pertaining to scientific literacy and SSIs, and the Learning study discourse to consider how lessons could be best oriented toward a balanced SRSE approach.

Table 9

Examples of explanatory dimensions for the first category of description.

Explanatory Dimensions	Category of Description ‘Approach to SRSE’
	1. Developing a balanced stance to new socioscientific issue-related curricular initiatives
Students’ level of participation	*Engaged critics* for future decision making as demonstrated through critical questioning and class discussions.
Object for student development	*Cognitive and conceptual* dimensions of the scientific concepts behind, context around, and harm caused by SSI. Students need knowledge and skills to be engaged critics.
Orientation to socioscientific issue engagement	Challenges: perceived lack of content knowledge and imposing values on students. Strategies: *building* a learner’s disposition toward self and ability to critique personal values.

This provided a platform for them to consider how they might collectively mitigate the challenges they encountered. These included how the teachers could approach their perceived lack of SSI content knowledge and feelings about utilizing power differentials to impose values on students. These areas, which the teachers perceived were in their loci of control, were built on and expanded through the Learnings study discourse. The teachers learned to critique their values and posture a learner’s disposition toward self. Consequently, the teachers could collectively examine the possible inclusion of a balanced stance to new SSI-related curricular initiatives, with a consistent agreement on the importance of this aspect to their classroom teaching.

4.2 Approach #2: Promoting Individual Transformations Through SRSE

In the second category, the teachers' viewed SRSE as promoting students' individual transformations. Initially, individual 'transformative learning' was defined by Mike:

(21) Mike: A transformative learning experience is about changing the orientation that we have in terms of how we're going to move about in the world. If I have a real pro-ecological mindset, that's going to affect my actions of how I go to the grocery store or how I get from A to B, how I recycle, how I plant my own garlic. That kind of thing. (Group 4, 34:59)

In this excerpt, Mike focuses on students' need to feel levels of responsibility for SSIs and to use that responsibility as a grounding force to establish *personal actions*. This is students' level of participation with SSIs (Table 10, row 3). At the end of the Learning study, Dave and Nicole provide similar definitions of what individual transformative learning is and why promoting it is an important goal for student learning.

(22) Dave: I think when students explore their individual psychology a little bit, the subconscious, and bring it into the conscious, you actually open up the possibility for lifelong learning, a lifelong scrutiny of your own upbringing. What are your prior beliefs? What are your reactive tendencies? What socioeconomic bracket did you grow up in? How was that influenced your perceptions and your ideas on things now? How could those influence others' beliefs? I think that's something from an SRSE standpoint that is important to integrate into classes. (Int 2, 9:36)

(23) Nicole: In the future, when the pandemic is over, you don't care so much about the science, but what's really great is let's look at how this had such different effects on different people, on the environment, on the economy and how that can change our take on it. Some kids didn't like closed schools because they couldn't see their friends. Now? Well, now the kids know that some schools provide other kids food. We need to do our part, right? I would do this again for the next three or more years after the pandemic is done. (ISM 6, 40:39)

In these examples, Dave points to the need for students to scrutinize their upbringing to clarify and develop their own opinions. Using her research lessons as an example, Nicole reflects that the science her students learned about pandemic control measures was necessary, but the 'really great' part was how the lessons influenced students' attitudes towards the pandemic and pandemic control measures. These included how those measures impacted different biotic and abiotic communities, how that understanding could change students 'take' on the issue, and how different 'takes' could provide paths for future personal action. In all the excerpts, it is apparent that the teachers were aiming to gestate pro-environmental, sustainability, and other socio-ecojust mindsets in their students – aiming to develop their attitudes and beliefs – so that they could derive their own opinions on issues and think about what to do next (e.g., 'planting their own garlic').

In preparing students to think about 'what to do next' (i.e., develop students' personal opinions and actions), Dave, Nicole, and Mike focused on developing students' *attitudes and beliefs*. This is the object the teachers deemed essential to act upon to engage students (Table 10, row 4). They sought to develop the dispositions, reflective capabilities, and thought processes needed for critical decision-making that, in turn, would influence personal actions. To do so, each teacher had students derive their opinions on SSIs and propose ways forward, as will be detailed below. Additionally, in planning to enact, enacting, and watching their colleagues enact this approach, the teachers developed pedagogical insights and personal reflections that facilitated continued engagement. These insights and reflections contribute to the robustness of this category and its active description. It highlights how the teachers experienced *promoting* individual transformations, including setbacks and breakthroughs.

The analysis of teachers' utterances revealed that the teachers perceived these insights and reflections as being both within and beyond their locus of control. For example, students' skills from prior courses and the context in which the teachers work. Both are within and beyond teachers' control in that they can provide the opportunity for student learning or their context to engage in ways they deem essential for the transformative SRSE approach. However, they cannot mandate that opportunity be taken. As such, the teachers' orientation to SSI engagement in this approach was labelled '*negotiator*,' found in the last row of Table 10. In being perceived as internal and external, the teachers negotiated with others, seeking ways for their students to take the opportunity transformative learning could provide.

In the following sub-sections, I provide evidence for each explanatory dimension found in Table 10, which is then summarized in Table 11. I begin by detailing the teaching experiences most representative of the category, highlighting the first two explanatory dimensions. This is followed by central challenges the teachers identified and addressed, showing the final explanatory dimension. Each subsection contains teaching experiences and central challenges. Their order was chosen for ease of presentation.

Table 10

Explanatory dimensions for the second category of description.

Explanatory Dimensions	Category of Description ‘Approach to SRSE’
	2. Promoting individual transformations through SRSE
Students’ level of participation	Personal actions
Object for student development	Attitudes and beliefs
Orientation to socioscientific issue engagement	Negotiator

4.2.1 Nicole’s Research Lessons and Addressing How Best to Support Transforming Students' Beliefs Given Student and Personal Inexperience

An experience representative of this approach to SRSE came in Nicole's second and third research lessons. According to Nicole, she aimed to expand her students' lenses on the differential effects of COVID-19 control measures so her students could justify which should be employed. First, Nicole had students discuss the articles they read in the previous class, prompting them to highlight various environmental, economic, and social impacts of COVID-19 prevention measures. From this base, Nicole utilized a future web to aid students in deliberations about which pandemic control measures should be most stringently implemented. A future web is a stake holder analysis tool that showcases the direct and indirect consequences of certain choices and the consequences of those consequences in an expanding web. These consequences can then be labelled as the web is analyzed, for example, looking at the positives and negatives of each consequence, connections between them, and other similarities.

For Nicole, students' realizations of the different effects of COVID-19 control measures as facilitated by the web stood out. As an example, in the pre-survey, she noted that most of her students thought the main consequence of COVID-19 measures was the inconvenience of wearing a mask. Now, her students had a different take. As Nicole explains:

(24) **Nicole:** I was sitting there when I was like watching, I was like, this is awesome like no one came back to I hate wearing a mask. It was rarely about them, or if it was about them, it was more about their position. That idea, of them being able to recognize some of their privilege on a bigger scale was great. (ISM 6, 12:37)

(25) **Nicole:** The one group who realized kids actually get food from school that they wouldn't get elsewhere. And what happens if schools have to close? Right? I think that was a big eye-opener. (ISM 7, 9:46)

From these excerpts, Nicole highlights her students' increased compassion for those affected by COVID-19, and in the latter example, for students of lower socio-economic status and on lunch assistance programs. This demonstrates how Nicole felt her students' beliefs and attitudes were developed. Using the students' webs, Nicole then guided her pupils to take a stance on which control measures should be pursued, which they presented to the class. In the third research lesson, Nicole facilitated a class-wide discussion on which COVID-19 control measures students should more consistently follow based on what they learnt. This is an example of Nicole seeing students' level of participation as geared toward personal actions.

In the third research lesson discussion, Nicole depicted a student's response counter to the intent of the research lessons:

(26) **Nicole:** My final discussion with my one class where one of the students said, 'oh yes, I actually don't think everyone should wear masks. They're annoying. I don't want to wear one.' And the controversy that sparked really brought home the purpose of what we were doing in these lessons. It allowed the students to try to actually articulate all the things

> they had learnt from the last few lessons in a way that they were kind of moving into that action phase without knowing it. Because part of their action was actually convincing their peer that they should be following the safety regulations. (Group 7, 14:31)

In this example, a student concluded not to wear a mask. Nicole felt two things were important from this example. First, it provided a forum for her students to engage in personal action (i.e., trying to convince their peers), which Nicole deemed essential. However, there was still the issue of her one student trying to justify not wearing a mask. This prompted a more extensive reflection, shared by Mike and Dave, around how to best approach developing students' beliefs more generally. Two related pedagogical insights came to the fore that can be subsumed under the term pedagogical content knowledge (Cochran et al., 1993). The first relates to students' skills when engaging in transformative learning activities. The second is the teachers' skills in facilitating that learning. Both represent a challenge the teachers encountered in the transformative approach to SRSE that are within and beyond their locus of control. As shown below, they addressed these challenges by negotiating their SSI engagement with their students and each other.

Focusing on what skills students possess before engaging in transformative learning, Nicole recognizes that some of her students' past learning experiences might impact their ability to engage in new ones. For example, Nicole expressed that the science teaching and learning culture at Cranberry High often relies on "memorize and do a test" (Int 2, 5:05). This strategy is acceptable for specific learning outcomes and perpetuates specific learning skills as a result. Still, as seen with Nicole's research lessons, these outcomes and abilities were not favoured. Nicole continues:

(27) Nicole: I don't think we've had a class where it's like you're now constructing your knowledge, reflecting on an issue, formulating an opinion. Maybe that wasn't in the zone for that group and that's why it was so hard for them. They were also on Zoom last year. There wasn't necessarily always this degree of collaboration. I don't know that what we did today is common. (ISM 6, 22:18)

In this passage, Nicole also ties the differences in teaching and learning approaches to the online learning of the previous year. On Zoom, Nicole commented that collaboration was more difficult, resulting in underdeveloped learning skills. In the same sphere of cooperation, Dave feels that what discussion skills students possess, especially around SSIs, can hinder transformative learning:

(28) Dave: The biggest problem I think with SRSE, with students talking, discussing, learning from that, is cognitive dissonance. They don't get to disagree or hold two ideas at once in a discussion. To practice that. Especially in science. Like, you say a controversial topic and then it gets tense and then, 'well my Dad says', you know what I mean? I think that's a huge barrier to actually doing SRSE. (ISM 4, 5:02)

In this excerpt, Dave notes that when students possess some discussion and reflective skills, transformative SRSE that relies on the transaction of ideas becomes easier to achieve. Like Nicole, Dave notes these skills may be foreign to some students, especially in science learning contexts.

Building off these insights, Mike provides a summary when reflecting on the learning tendencies of his students after Nicole had shared her pre-survey data: "I spent a lot of time trying to understand their culture of learning. And with each grade, you've got a different kind of challenge because those kids have had however many years of a way of being" (Mike, Group 5, 44:28). In this excerpt, Mike summarizes Nicole and Dave's initial insights: that students have 'ways of being' at a school based on years in attendance. These ways of being necessarily influence learning since they direct what learning skills students implicitly developed years prior. This point is salient given that the new ways of learning pursued in this category differ from the existing ‘culture of learning.’

Reflecting on Dave's research lessons, in Group Meeting 9, Mike expresses how he was more proactive in helping his students to develop their presentation skills given his understanding of their previous experiences:

(29) **Mike:** This carbon emissions project was their third opportunity to present and do something like this. The first one, the presentations were terrible. They were brutal. But the second presentations, it was quite a lot better. But what happened in these presentations was so unique because they’d learned in this way before. Third time, right? (Group 9, 30:51)

In this example, Mike notes the importance of scaffolding students' skills, or negotiating his expectations in view of student readiness, to engage them in new teaching and learning approaches Another example comes from Dave and Nicole. Early on, Dave was skeptical that his students might require additional support. He explains after hearing about Nicole's pre-survey results:

(30) **Dave**: I think [social and ethical considerations] are common. All students can think through those, discuss them. These kids are in a university course, they know what social and ethical means.

Nicole: Well, you said all my students can do my stuff. And we did the survey, and they can't. (Group 5, 42:45)

In this excerpt, Nicole speaks from experience – her students' pre-survey results showed their inability to articulate the cons of COVID-19 restrictions outside of 'masks are uncomfortable' – and she cautions Dave against making assumptions about students. Following Dave's pre-survey, he notes in Group Meeting 8:

(31) **Dave:** So, they didn't really know what social or ethical implication meant or what to do with it. Like over half had no clue. (Group 8, 38:38)

Vindicated, Nicole suggests that Dave prime his students with a pre-research lesson, scaffolding their social and ethical discussion skills before the more formal classes begin. Dave initially hints at the scaffolding idea by relating it to his farming practices vignette (Appendix I).

(32) **Dave:** The farming techniques conversation is a separate thing, but it's a good warm-up to [the research lessons], I would say. But there was still some hesitancy. I mean, still, about a third of the students said that 'I don't know what a social implication is' or how to talk about one. (Group 8, 44:14)

(33) **Nicole:** Well before you jump into an SRSE formal or focused assignment, maybe the assignment before has elements of SRSE in it just to warm them up. (Group 8, 50:27)

In this exchange, Nicole suggests Dave should do a pre-research lesson to ensure students' discussion skills are 'warmed up.' Dave agreed, commenting:

(34) **Dave:** So, I'll role model some of these skills which is really powerful and something that Mike and Nicole have reminded us all, that it's powerful to scaffold the process. (Group 8, 51:23)

In this excerpt, Dave expands on Nicole and Mike's insights. However, in this pursuit, the teachers also found their skills as educators in facilitating the desired learning deserved focus.

Mike, Dave, and Nicole recognized the importance of their skills in facilitating transformative learning. Dave brings this up, focusing on his inexperience with leading discussions as a response to his earlier reservation about students' discussion skills:

(35) Dave: That's something I've always known has been a limitation for me as a teacher. I think my strength has been showing them very compelling chemistry demos and reactions and stories about freckles and why they exist. But getting them to discuss, consider different views, develop opinions, facilitate that, that's something that I could add to my practice more. (ISM 9, 8:36)

(36) Dave: And to be honest, I'm going to have to, to read up on that a little bit. And I mean, I can think of examples as we read case studies in the textbook. But this is something I haven't done, discussed the social and ethical beyond the obvious. (Group 5, 54:50)

In these excerpts, Dave is honest about teaching limitations he perceives as necessary to transformative learning: facilitating student discussions and discussions in the context of social and ethical implications. Similarly, Mike focuses on the minutia of an individual class in a post-lesson reflection. He's concerned not with facilitating a discussion but with having his students talk in the first place, noting they are "the quietest class I've had in 20 years" (ISM 13, 7:14). Nicole was most concerned with how to expand her students' lenses outwards.

In each case, the Learning study group provided directions. Mike relayed to Dave questions he could pose to students when thinking about social implications and where to find them. Mike explains during Dave's research lessons planning meeting:

(37) Mike: I looked at pipelines for a long time. That's an example of one really deep dive into something. So, I have questions about that. At the beginning of every unit, every other unit, you know, there's questions you can ask or get students to look at, too. It's emergent, it's a real-world application. (Group 8, 57:43)

In this example, Mike leverages his prior experience teaching AP courses and his knowledge of pipelines to provide recommendations for Dave's perceived inexperience. Similarly, during a planning period of Nicole's research lessons, Dave reiterated to Nicole the possibilities of future webs after she had already read about them in Hodson (2014).

(38) Dave: I was just skimming, but there's those future wheel things in Hodson.

Nicole: Future webs? We talked about those. But good point. (Group 4, 39:47)

In this example, Dave aimed to help Nicole explore ways to expand her students' lenses outwards, even though she had already considered that approach. For Mike, strategies were forwarded by the group following one of his lesson debriefs to prompt students' classroom contributions and discussion. In all examples, the Learning study group negotiated with each other's practice to explore new strategies to best enact the transformative approach to SRSE.

4.2.2 Mike and Dave's Research Lessons and Addressing How Best to Engage with the School Context

For Mike, the transformative learning approach to SRSE is represented by his second, third and a portion of his last research lessons. In lesson two, Mike first had his students share highlights from conversations they had with their families about which potential carbon emission reduction actions might be most appropriate. In this instance, Mike felt he was ensuring his students were attuned to the beliefs, interests, and values of those most likely responsible for his students carrying out their projects: his students' caregivers. As Mike explains:

(39) Mike: Part of this project was about making agents of change in a household. Talking to people they're close with to understand what's going on. That's a safe place to start.

> The one project, the student did it so their parents could actually consider putting solar panels on the roof. Come on, that's pretty darn cool. (ISM 14, 14:32)

In this excerpt, Mike highlights one student's proposal to put solar panels on their roof. Like Nicole's aim of expanding her students' lenses through future webs (i.e., a form of stakeholder analysis), in this framing, one way Mike aimed to develop attitudes and beliefs was for his students to be exposed to different views on lowering carbon emissions and having practice in discussing possible actions. The focus on this student putting solar panels on their roof is also an example of Mike viewing students' level of participation as geared toward personal actions. From this expanded understanding, Mike facilitated his students in researching the various measures they discussed, having them choose and justify one to implement.

This research-focused lesson, lasting two classes (one was a work period), was rife with conversations in which students were supported in deriving their own opinions on carbon emission reduction actions and proposing personal ways forward. Examples included deliberations on "vacationing thoughtfully" and how a student might grapple with "flying to Hawaii or driving to a vacation spot" (Mike, Group 10, 32:04). It was observed that this included the nuances of a person's needs/wants, the carbon emissions of flights, and wealthy individuals' capacity to circumvent restrictive legislation. Another example observed included the differential impacts climate change had on countries with lower Gross Domestic Product, who should pay for the disproportionate effect climate change was having on these nations and the work of advocacy groups in bringing these ideas to light. As homework, the students prepared presentations on which action they wanted to take, including mathematically justifying how the action would reduce their carbon emissions.

In lesson three, the students presented their projects. Student presentations included the impacts of tree planting along busy urban roads, the carbon saving of driving to all vacation destinations versus flying – from the previous example, this student reasoned that one return flight per year was a happy middle ground – and the impacts of eating locally concerning supply chain emissions. Mike was consistently impressed by his students' presentations: "I mean his project was way past Grade 9, they were so, so sharp and nuanced. You could see they weighed a lot of different parts from the entire Unit" (ISM 14, 10:04). This excerpt highlights Mike's view of students' increased communication skills and specifically their ability to articulate critical ideas from differing perspectives. These features demonstrate a way Mike felt students had engaged in transformative learning.

Mike felt his students' presentations made another salient insight. As he explains to the group in his research lesson debrief:

(40) Mike: So, there's a Venn diagram I want to talk about today. It's of the conceptual, the contextual and the critical, you put those together. It's like, hey, the middle, that's a sweet spot. Some people might only go to the blend of the conceptual and the contextual, and that's fine. That's probably better than if they're not doing any. But if you can go to that intersection of all three. Magic.

Nicole: I think that's true; the students can pull on all of them at once. You want the overlap of the three opposed to one.

Mike: Yeah. It's when the three are overlapping. That's what happened with my students' presentations. All three.

Dave: Well, that, that's actually, wait. That means you could blend any of the two in a Venn diagram. Like what does trying to do the blend of conceptual and critical, what would that look like? Without context...

Mike: Oh great, keep me up until two in the morning again. (Group 9, 47:10)

In this example, Mike pulls from his students' presentations to theorize with the Learning study group about the continuous nature of the 3-VSL. In this case, Mike and Nicole felt that the students' presentations represented a coming together of all three Visions rather than being any one alone. As seen in several examples above, this is another instance of the teachers drawing on the theoretical perspectives of the Learning study to more fully understand their practice and its connections to student learning. In the first half of the fourth lesson, Mike held a debrief of student presentations to capture their feelings on the entire climate change unit.

For Dave, the transformative learning approach to SRSE is represented by his third and fourth research lessons. Dave's research lessons were focused on a student project. His object of learning was: developing students' ability to analyze and discuss the social, ethical, and environmental implications of emergent research in the Unit Land and Water Use.

The project had three main components. Dave explained that first, students would explore the concepts behind a science article and make connections to their coursework. Second, students would lead a class discussion on a social and ethical consideration related to the article read. In the discussion, an SSI was to be introduced to concretize the social/ethical aspects. Third, students were to put forward a 'personal challenge' they could undertake to address the SSI.

In the first two portions of the project, Dave expressed his desire to ensure the concepts behind, context around, and harm caused by an SSI were covered. In those portions, there is evidence of the balanced approach from Category #1. However, Dave framed the rest of the project more in line with the transformative learning approach of this category. As an example, in part two of the project, Dave sought to guide students to reflect deeply about "their own bias, upbringing, tendencies" (ISM 10, 25:45), which he felt were antecedents to discussing and analyzing social/ethical considerations. In part three, students chose a justifiable course of action they could take at a personal level.

As mentioned with Mike's 'bird strike' example and three-part Venn diagram, or Nicole's knowledge domain reflection, in the final interview, Dave explained that this assignment was designed based on the 3-VSL:

(41) Dave: I used [the 3-VSL] to reflect on my research lessons. Because I found myself thinking, what is my assignment missing? What can I meaningfully add? So, I did that personal challenge. Yeah, it was a little haphazard at times, but it was good. That little piece in there about a personal challenge to self, like I think that's actually really good. I think I'd like to do that a bit more. (Int 2, 56:56)

In this excerpt, Dave explains how the 3-VSL pushed him to evaluate his project and consider what else could be added (e.g., adding the 'personal challenge' portion). This is another example of the teachers drawing on the theoretical perspectives of the Learning study to more fully understand their practice and its connections to student learning.

To implement this project, Dave used four research lessons. First, he modelled the entire project himself based on the SSI of overfishing. In the presentation, he focused on his personal story and bias to frame the exploration of others' views. Dave deemed personal introspection a critical component of transformative learning. He explains:

(42) Dave: In a nutshell? SRSE is healthy skepticism of the world to promote positive change. So, we need healthy skepticism of the world, of media, but especially of our own thoughts and that which has been shared with us from family and relatives to

> really consider other people's ideas. The subconscious to the conscious, right? (Int 2, 26:08)

Like Nicole and Mike's aim of expanding their students' lenses, in this framing, to develop attitudes and beliefs, Dave focused on the need to be skeptical of self and others before making justifiable choices.

In the subsequent classes, Dave makes this point a priority. In the following research lesson (lasting two classes given an added work period), Dave aimed to ensure students reflected and negotiated their personal histories before coming to a personal challenge. One example included a group of students' deep affinity for fishing and catching specific kinds of fish (e.g., endangered ones). Dave aided students in thinking about why those particular fish were important to them. He then probed students to consider why catch and release might be a favourable practice for the continued flourishing of fish stocks. Like Mike and Nicole, the suggestion of catch and release, as a personal challenge Dave's students could take on, is an example of Dave viewing students' level of participation as geared toward personal actions.

In the final research lessons, the students presented their projects, highlighting the personal challenge they derived. A student example included the SSI of deep-sea mining, the ethical dilemma of harming the environment (e.g., deep sea reefs) versus the need to extract materials for renewable energy technology, and the personal challenge of setting up an electronics recycling system at the school. Another included the SSI of overfishing, the ethical dilemma of dwindling fish stocks versus the want to catch rare fish, and the personal challenge of sharing the OceanWise app to educate others about sustainable harvesting practices.

Noteworthy from this example is Dave perusing transformative learning outcomes in an AP course. As Dave notes:

(43) Dave: What is morally and ethically right, in my case? Teaching them to think or teaching them to write the Advanced Placement exam? Because the exam doesn't teach thinking that well, it teaches memorization. It's all conceptual, or below conceptual in some cases. Like we can do the Research Cafe, and the SRSE, but how you test is sometimes not a reflection of that, and it can limit what you do in the class. (ISM 9, 10:36)

In this excerpt, Dave names a challenge of pursuing transformative learning with his students. In this case, it's the AP exam. It is often used in post-secondary admissions. At Cranberry High, post-secondary admissions are an explicit school goal, so high-stakes assessments are important. From Excerpt 43, Dave does not see transformative learning as preparing students for the exam.

This challenge is an example of a personal reflection Mike, Dave and Nicole had to work through as they enacted SRSE aimed at transformative learning. How best to engage with their school context? At Cranberry High, the teachers felt there was an incongruence between some of the intentions, practices, and products of individually transformative SRSE and the demands of the school. Continuing to highlight Dave's experience as representative of Mike and Nicole's, Dave notes before and at the end of the Learning study that high-stakes assessments are not the only school-based pressures which may hinder transformative learning approaches.

(44) Interviewer: So, what might be some challenges with SRSE focused on individual psychology?

Dave: The biggest factor, two hundredfold more important than anything, are perceptions from colleagues and families (Int 2, 46:56).

(45) Dave: With hard systems in place, with words like ‘alignment’, it’s just the devil of SRSE. Because what you're telling me is I need to do exactly what’s always been done and I can't do SRSE. It's like swimming into a massive river upstream. (Int 2, 37:33)

In these excerpts, Dave points to the power historically embedded traditional science education has on the uptake of new approaches. These factors are part of the demands of schooling at Cranberry High. Dave reflects with Nicole on this power during Group Meeting 3:

(46) Dave: Like**,** I'm trying baby steps with this and I'm getting like ‘breaks’ [car breaks], just break, break, break.

Nicole: I would say, well, so I would say at the younger grade levels, there's a little less ‘break’ because there's a little less ‘mark.’ (Group 3, 19:36)

In this excerpt, Nicole connects senior science marks and university prep. She indicates a solid pull to conform to traditional teaching approaches when high-stakes exams or course marks are used for post-secondary admissions.

While this is a reality for Dave, Nicole and Mike, teaching research lessons in Grade 8 and Grade 9, respectively, their reflections had little to do with mandated curriculum, grades, standardized tests, or parent expectations. This is because, at Cranberry High, Grades 8 and 9 are seen as having more freedom for teachers to pursue learning skills. After all, marks are seen to matter less (e.g., ‘less break’). Accordingly, Nicole and Mike’s challenge arose from the traditional science teaching and learning culture. In enacting transformative SRSE, they were increasingly expanding science education norms to new areas, directly brushing up against the expectations of school community members. Nicole brings this up with Dave in Group Meeting 3:

(47) Nicole: I think I reflect on expanding culture. Because I think this is pushing to a different area. So, I think inherently by trying to do 'this,' SRSE, that's actually ... Something else we're trying to do is figure how we shift and diversify what science is and means.

Dave: Yeah, it's like there are two pathways: one pathway is to the students, maybe vertically. And then there's the horizontal axis, the, this [waves arms in gesture to school around him]. The more difficult one. I mean, SRSE is for our colleagues, probably harder than it is for the students. (Group 3, 16:28)

In this exchange, the vertical axis refers to student knowledge, experience, and skills in relation to SRSE, while the horizontal axis refers to the broader science teaching and learning culture of the school. Nicole highlights that expanding what 'science is and means' along the 'horizontal axis' presented by Dave is a challenge for enacting individually transformative SRSE. In her case, while the parent, student, and curricular tensions might not be as present, teacher-teacher interactions, as alluded to by Dave, still provide moments of tension. Later in the Learning study, Nicole recognizes that "what we have is more of a difference of values or how we think we do our job best. To some, memorize and do a test is a big part" (Nicole, Int 2, 5:05). Echoing the teacher-teacher tension, Mike explains in Group Meeting 4 after a recent science department meeting:

(48) Mike: That is what this morning's science meeting was about. Can we move so that we're not abandoning this pillar [conceptual] but can we see that there are other pillars here to this beautiful structure? So, can we at least make it explicit that they (a) exist and that (b) that we're on this journey together with those other pillars? (Group 4, 11:28)

From this excerpt, Mike, like Nicole and Dave, does not argue that traditional school science approaches are unnecessary. The conceptual ‘pillar’ needs to remain to hold up the entire ‘beautiful structure.’ Instead, challenges arise when no expansion is considered or condoned. As such, the teachers had to negotiate how a transformative SRSE approach could be put into practice considering the pressures (e.g., colleagues' interpretations of the mandated science curriculum, expectations of students, parents' perceptions, and values around what science education is and means) brought on by the demands of their context.

The impetus to negotiate came first from administrative support. The school administration recognized that expansions in practice for the science department were necessary. As an example, at the end of the Learning study, Faye notes: “How can I effectively spread these SRSE ideas through our science department? Because you have some traditional people who have been doing the same thing, the same way, for a long time now” (Int 2, 12:26). This ethos was kept throughout the Learning study. Faye often pushed the teachers to lead in this area in line with other innovative school initiatives such as Debate Club or Model U.N. (Debate Club and Model U.N. are student co-curricular groups which often focus on social issues and their resolutions).

Through continued negotiations supported by the Learning study's discourse, the teachers carefully considered the expectations of parents, students, and colleagues in a manner that respected their views but still attempted to shift the needle of what science is and means. For example, despite his reservations, Dave continued to plan SRSE approaches in AP classes. Dave explains at the end of the Learning study: “Aquatic and Terrestrial Pollution is all of Unit Eight, and it covers 10 percent of exams. So, that’s a good area for more discussions and debates and healthy skepticism.” (Int 2, 47:11). Dave also felt that a shift away from AP classes would be favourable to explore SRSE approaches more consistently. In this light, Dave considers Chemistry 11 an area that SRSE could flourish. He shares this during his research lessons debrief:

(49) Dave: It's evident now that I'm thinking about it like I need to bring some degree of the critical to Chemistry 11 because it's just dull as fudge. I'm looking forward to the green energy unit; we've got to do something with that (Group 8, 44:21).

For Nicole and Mike, their negotiated and supported strategies came from renewed convictions and a focus on colleagues. Nicole explains at the end of the Learning study:

(50) Nicole: I think throughout this, I've clarified what's important, like I need to be facilitating students' ideas, fostering more internal responsibility in our learners, especially because of the nature of most schools and how learning is more memory-rote-regurgitate. Like my job is that much more important. (Int 2, 55:26)

In this excerpt, Nicole notes that she wants to continue pushing individually transformative SRSE precisely because others might ignore it. For Mike, he takes a different route, which he explains in the whole Learning study debrief of Group Meeting 10:

(51) Mike: Model U.N. and Debate are core examples of such momentum. So SRSE doesn't have huge momentum. So, what has a big momentum here? It's conceptual literacy, right? You know, reaching that far end of the critical, well, do you reach the near end, towards contextual more, the close end of the critical? You're probably going to have a bigger impact aiming there because you're going to be seen as legitimized because if you're on the far right, in this school culture, it probably feels extreme to some or many. And so maybe what we're doing is planting seeds for them to begin their journey. (Group 10, 21:53)

In this example, Mike explains his desire to place focus on the science teaching and learning culture of his colleagues, aiming to ensure they could expand their practice towards individual transformative SRSE and components of critical literacy most in their comfort zone.

4.2.3 Category #2 Summary

In Table 11, I give examples of the explanatory dimensions for the second category of description to summarize this section. This category presents how the teachers deliberated upon and enacted an SRSE approach that focused on promoting students' transformations.

Table 11

Examples of explanatory dimensions for the second category of description.

Explanatory Dimensions	Category of Description 'Approach to SRSE'
	2. Promoting individual transformations through SRSE
Students' level of participation	*Personal action* choices in relation to SSI as demonstrated by taking a stance on an SSI and deciding what to do next.
Object for student development	*Attitudes and beliefs* toward SSIs through stakeholder analysis, interrogating bias, ethical reasoning, and decision making. Students use attitudes and beliefs as grounding for personal actions.
Orientation to socioscientific issue engagement	Challenges: deciding how best to develop students' beliefs given students and personal inexperience engaging in similar practices and how best to engage school context in that pursuit. Strategies: *negotiating* and scaffolding students' skills, *negotiating* from others practice, and *negotiating* with school context from a place of support.

The teachers sought to prepare students to forward personal actions on SSIs by developing their attitudes and beliefs. They drew from research lessons and the theoretical perspectives in the Learning study to consider how lessons could be best oriented towards individually transformative SRSE. This provided a platform for them to consider how they might collectively mitigate the challenges they encountered. These included how the teachers could best support developing students' beliefs given their students and their inexperience engaging in similar practices and how best to engage with their school context in that pursuit. The teachers found that negotiating and scaffolding students' skills, negotiating from others practice, and negotiating with their context from a place of support were crucial insights and reflections to enact this SRSE approach. Consequently, the teachers could collectively examine the possible inclusion of an individually transformative SRSE, with a consistent agreement on the importance of this aspect to their classroom teaching.

4.3 Approach #3: Promoting Students' Engagement with Collective Social Action

In the third category, the teachers' viewed SRSE as promoting students' engagement with *collective social action*. This is the students' level of participation with SSIs (Table 12, row 3). In this category, Dave, Nicole, and Mike sought to develop their students' agency so they might feel empowered to act on SSIs with others (collective action) and in ways that could impact people and systems at a broader level (social action). The focus on others is encapsulated by Nicole in Group Meeting 10:

> **(52) Nicole:** But I want to know how you get to the far side of critical action. How do you get to a place of meaningful change, whether climate change, wearing your mask, or keeping your distance? Are you looking at individual action the way I think most of us pursued this year, or are we looking at like group action? Should I have taken my class where well, how do we help our school move forward or our class? (Group 10, 24:06)

In this excerpt, Nicole highlights both the collective and social aspects of action the teachers focused upon in this category. First, she wonders if a focus on collective action – action taken as a class – might better support students in acting after reflecting on some of the research lessons. Second, by pitching this action at the level of the whole school, she aims to impact not only the individual students but other students and the system they inhabit. In Group Meeting 7, Faye explains the importance of the collective and agency concerning the SSI of climate change:

(53) Faye: I do want to say I just love the idea of making climate action a real, authentic, and collaborative task in kids' life like this. Your choices have consequences. And what are you as a family, are you as an individual, are you as a group prepared to do? What can we do? And so, just starting those conversations with each other where they start realizing that they all have an agency, and this is one of the big issues of their time. And you know what? It's something we can do now. (Group 7, 34:26)

In this excerpt, Faye had just heard Mike's plans to focus his SRSE research lessons on climate change. Though not fully developed, from Mike's initial explanations, Faye explains that Mike's classes have the potential to foster student agency as the entire class works toward similar goals. Faye feels students need this agency to act against one of the 'big issues of their time.' Mike echoes the importance of student agency and its connection to action at a broader level in Group Meeting 8:

(54) Mike: I want [students] to feel empowered that they actually can do something on a broader level. So that final project, the SRSE, is about, what can kids actually do and why would it make a difference. And then let's see if we want to do it. (Group 8, 16:37)

In this excerpt, Mike highlights his desire to connect the final portion of his research lessons to empowering students in acting at a 'broader level.' For Mike, this level is aimed at actions that have substantial impacts in mitigating climate change as opposed to the rhetoric to "reduce, reuse, recycle and compost" (Mike, ISM 8, 16:30). Moreover, Mike feels for broader level actions to have substantial impacts, they need to be carried out rather than only proposed. They need to be "active" (Mike, Group 8, 21:49). Nicole, Faye, and Mike's excerpts show evidence of an extension beyond developing students' attitudes and beliefs to *promote* personal decision-making and personal actions, as detailed in Category 2. Now, the teachers are focused on how students may *enact* those decisions, collectively, and in ways that impact other people and systems. Nicole and Dave provide further examples in their final interviews:

(55) Dave: I really want to help kids to drive around the city, use these test kits we have that look at aluminum and copper ... I'd love to see the kids generate graphs, and sample water, especially at the Timothy Royce River (pseudonym) from different sources downstream, maybe get some more parameters, some herbicides and pesticides that are common and look at their concentrations. Make a Google Earth map together of the data and then share that with government agencies, like, these are carcinogenic levels. What are you going to do about that? And then start to talk about why we are burning coal in this city. A group with a focus like that? Imagine that. That's like the next step. (Int 2, 45:31)

(56) Nicole: And that's where I think, how do you set them up better? And maybe that's the next step for next year is it's actually as a class, all of them researching, OK, great, this was our action proposal, like, OK, let's all dive into that. How would we actually do that? And then they can take the lead. (Int 2, 13:09)

In these examples, Dave and Nicole present hypothetical plans for enacting future SRSE approaches that aim to build students' confidence in acting. These excerpts are also an example of Dave and Nicole viewing students' level of participation at a collective level (e.g., done as a 'group' or 'as a class') and at a broader social level (e.g., Dave aiming at government agencies).

In preparing students to take collective social action, Nicole, Mike, and Dave focused on developing *students' agency*. This is the object the teachers deemed essential to act upon to engage students (Table 12, row 4). They sought to provide students with the support, encouragement, and opportunity to engage in activities that might mitigate the harm an SSI can cause. To do so, each teacher either provided or planned to provide the students 'action invitations' and 'action spaces,' as will be detailed below. As Nicole notes, action spaces are areas students can be supported in acting, and action invitations are the introduction and encouragement to join those spaces: "We want to create more space and encouragement so that if students want to act, they can" (Nicole, Int 2, 9:30).

In planning, enacting, and watching their colleagues enact this approach, the teachers developed pedagogical insights and personal reflections, facilitating continued engagement. These insights and reflections contribute to the robustness of this category and its active description. It highlights how the teachers experienced *promoting* engagement with collective social action, including setbacks and breakthroughs.

The analysis of the teachers' utterances revealed that the teachers perceived these insights and reflections as an interaction of internal and external factors (e.g., drawing on teachers' internal interests and positions and what their school context condones or hinders). This differs from insights and reflections perceived as internal *and* external based on how the factors prompted the original insight. In Category 2, the insights and reflections were initially driven by external factors (e.g., students' skills and the demands of the school context, both of which the teachers felt they had no initial control over). In Category 3, the insights and reflections are prompted by an interaction of internal and external factors (e.g., the assemblage of teacher, student, and school-based positions driving SSI topic choice). For this approach to SRSE to be employed, the teachers had to champion a way forward, overcoming the interaction of internal and external factors to advocate for an approach they believed students required. As such, the teachers' orientation to SSI engagement was labelled as '*advocate/champion*,' found in the last row of Table 12.

Table 12

Explanatory dimensions for the third category of description.

Explanatory Dimensions	Category of Description ‘Approach to SRSE’
	3. Promoting students’ engagement with collective social actions
Students’ level of participation	Collective social actions
Object for student development	Student agency
Orientation to socioscientific issue engagement	Champion

In the following sub-sections, I provide evidence for each explanatory dimension found in Table 12, which is summarized in Table 13. I begin by detailing the teaching experiences most representative of the category, highlighting the first two explanatory dimensions. This is followed by central challenges the teachers identified and addressed, showing the final explanatory dimension. Each subsection contains teaching experiences and central challenges. Their order was chosen for ease of presentation.

4.3.1 Mike’s Research Lessons, a Lunch Seating Policy, and Addressing if it is Right to Impose Action

An experience representative of this approach to SRSE is seen when Mike provided his students with a 'Hope To' invitation as a space to carry out and reflect on their carbon emission reduction presentations. Mike explains in Group Meeting 8:

(57) Mike: 'Hope for' versus 'hope to.' Hope for is passive, and hope to is active. So, I'll call it soft action because they're not becoming, you know, militant environmentalists out there putting a stake in the ground and telling parents not to drive. That would not be appropriate in my mind. But it's what would feel like a really cool action that they could take on. And, hey, if it only ends up being three or four kids that do it, then it's three or four kids that did it well and might do it more in the future. (Group 8, 21:49)

In this excerpt, Mike details his plans for culminating his research lessons and students' carbon emission reduction projects. In the last half of his fourth research lesson, he explained to his students that there would be a space for them to reflect and report on the enactment of their projects. Focusing on building student agency, Mike also aimed to ensure his students would be supported. Mike indicated he would be doing a carbon emission reduction project by biking to work every day – something he had been doing anyway but now shared with students – and should students want to discuss their projects in relation to his, he was available. Mike also indicated that he could support students in any aspect of their projects during class or after school should they deem it necessary (e.g., how best to bike in the rain). Both offers of support aim to develop students' agency and also highlight Mike's positioning of students' level of participation at the collective level. Students would be supported in their projects with Mike and with each other – they would not be acting alone, rather, all acting toward similar goals of reducing carbon emissions. Moreover, they would be living out their carbon reduction proposals, and thus acting at a broader level. Following the introduction, Mike had students sign up to 'hope to,' and 85% of his students agreed. The class decided to present their work 'officially' on Earth Day (an annual event to support environmental protection [Earth Day, 2023]) in six weeks.

The choice by Mike to invite his students to act out their projects was a shift and represents a personal reflection the teachers encountered in this approach to SRSE. Initially, the teachers expressed skepticism toward engaging students in action via comments like " that's a red flag, red flag" (Nicole, Group 8, 53:36) and "that won't work here" (Dave, Group 3, 8:05). Mike even described SRSE as "socially *irresponsible* science education" (Mike, Int 1, 6:05) owing to the "militant activism" (Mike, Group 2, 11:05) with which he perceived Hodson (2014) to have approached the critical Vision. The group initially perceived Hodson's activism as being too controlled and directed by the teacher. They viewed it as imposing action on students, which they felt was irresponsible. Recall Mike's earlier comment regarding a teacher who brought their students to a protest: "And I thought [they] should be pulled over the coals for this" (Group 2, 14:42).

Dave, Mike, and Nicole's skepticism of 'imposing' student action is based on two reasons. First, they felt that students already knew how to engage in action, and it would be superfluous to use class time to follow that route. Second, there were questions about whether action would fit their year, imposed or otherwise, and whether it was right to force students' engagement. Though each teacher brought up these points throughout the Learning study, Mike's experiences of the former will be focused on due to his use of practical examples.

In one of the Learning study meetings, Mike described a teaching vignette where he had students leverage what they had learned in class to construct poignant questions for various SSI stakeholders. Mike explained that these questions were intended to inform students' future decisions by showcasing different sides of an issue (evidence of Category 1). However, Mike also explained that articulating those decisions in class, formulating a plan of what it could look like, and living that choice were not things for which he was comfortable giving class time.

Encouraging any of the three options was viewed as irresponsible. Reflecting on the vignette, Mike notes that he and his colleagues "felt similarly in that [they] do not influence the students about what their decision is. And [they're] never going to ask them to make a decision either. That's irresponsible" (Mike, Int 1, 1:00:20). That said, should a student decide to pursue an action, Mike was ready to support. As Mike points out during the final interview:

(58) Mike: The irony is that if I had done this project at Pearson Secondary (pseudonym), I know that the outcome would have been very different with respect to the 'Hope To' invitation. When you look at the Pearson Environment Club (pseudonym) – the Head of that wasn't driving what they were doing; she was just helping facilitate what they wanted to do. But they built a garden. And so now they sell produce from the garden. But they set up the conditions for the kids to engage in, you know, where the kids went with this. And the kids took it. (Int 2, 1:03:13)

In this excerpt, Mike relays that at his previous school, Pearson Secondary, students seized opportunities to engage in action and were met with supportive faculty. As such, Mike felt there was no need to mandate action because students were already willing and able to do so. Mike extended this lesson to Cranberry High and concluded in the Learning study that if students want to act, they would because "they know full well what they can do, right?" (Mike, Int 1, 1:01:40).

However, what if the students don't know what they can do? In Group Meeting 2, Mike describes an instance like this:

(59) Mike: I was working with students in an environmental leadership class. And, 'action?' That's what, where I was before, action was a big component that was student-led; it wasn't teacher-led. And 'here' was an interesting feeling. There were barriers to action. And not that I was pushing for action, but I wanted to be facilitating in helping them think through what their action might be. But it was so foreign to them.

Nicole: Well, I think this is like Hodson saying. Is if you never teach students how to take action, they have no idea how to do it. So, if we're not exposing them to how you might take action, when will they ever learn? (Group 2, 23:42)

Based on Mike's example, in this exchange, Nicole echoes Hodson's (2014) argument that action must be taught to students for them to be able to engage with it. According to Nicole, simply leaving it up to the students likely means no action would occur.

Indeed, similar scenarios played out in their research lessons as the teachers worked with the idea of 'barriers to action' at Cranberry High. For Dave, although his students proposed personal challenges they could take to address SSIs, he felt very few of them were poised to follow through. He explains a few weeks after his research lessons:

(60) Dave: I didn't see any actual plans of them doing their challenges (ISM 15, 36:08)

For Nicole, barriers to action were murkier. On the one hand, in one of her final research lessons, a group of students partnered with Nicole to take collective action. In this scenario, Nicole led the class in a debrief. Some students mentioned that the school-based policies for COVID-19 reduction were inadequate, given how far fomites (or droplets containing a virus) could reach. Nicole reflects in her research lessons debrief:

(61) Nicole: They wanted more spacing in the tent, so people are further apart. Like it's kind of neat, I took action by telling admin about it. But it was based on their proposal or what they thought wasn't working. The action was proposed by them. So, I just executed their idea. (Group 7, 19:45)

From this excerpt, Nicole explains that her students' wanted lunch seating plans for lunch to be more socially distanced. Nicole then acted out this proposal by taking it to administration, and the seating arrangements at lunch were modified. However, even given the modifications, Nicole still observed her students flaunting school-based rules designed to slow the spread of COVID-19. As Nicole notes, her students were still "not distanced at lunch, and masks off" (Group 7, 8:34).

For Mike, not one student engaged in his 'Hope To' invitation: the space provided on Earth Day to celebrate their carbon emission reduction projects remained empty. Mike explained the disappointment of this result in his final interview: "Well, I put out the 'Hope To' invitation, and nobody took it. I'm disappointed" (Mike, Int 2, 51:58). These experiences of students' not following through with their proposed actions, and in Nicole's case, needing teacher support, pushed the teachers to realize that when actions are not appropriately scaffolded, in this context, they are unlikely to occur.

The original assumption that students would act at Cranberry High without scaffolding was proven false for Mike, Dave, and Nicole. This was a critical insight and reflection within this approach to SRSE. However, the teachers now wrestled with how that scaffolding might happen. For example, Nicole wonders if action could be pursued in the teachers' current context, given the science teaching and learning culture and the reduced class time brought on by the pandemic. Discussing with Faye in Group Meeting 4, she points out:

(62) Nicole: Would you argue that we have to act to be in the critical Vision?

Faye: Nobody, not many kids are acting on things. Occasionally maybe. But not on hot-button issues.

Nicole: Because I want to say I'd like our students to recognize harmful socioscientific issues and maybe think about some actions we leave up to them. But whether they go there or not is not, I don't think, within the scope of our time or other factors and with how we're able to do this study this year. (Group 4, 57: 39)

In this excerpt, Nicole wonders if action could be pursued with students based on the constraints of the year and context. Nonetheless, Nicole advances the possible ways to scaffold action in this excerpt, now ensuring students minimally know some steps they can take (in line with the pedagogy of Category 2) but leaving the rest up to them.

Throughout the next several Group Meetings, the teachers reconciled how best to scaffold student action without mandating it in class. Eventually, they settled on a middle ground between imposing action and no action, choosing 'action invitations' as the space students could inhabit if they desired. As Dave explains in Group Meeting 9:

(63) Dave: I think we're looking at the curriculum, the competencies, and saying, yeah, these are times when we can and should be getting an invitation to our students to act and saying that this is a responsibility that we have, and we should take up that challenge (Group 9, 55:25).

In Dave's excerpt, he summarizes the teachers' views that students needed to assume some ownership for their actions by seizing opportunities presented to them by their teachers. The teachers realized that action needed to be both student- and teacher-led in this context. Nicole echoes this point in Group Meeting 10:

(64) Nicole: I think you always run up against, like, what's morally right? Do you force your kids to act, or is it an invitation to action? And it's hard to say. In one high school project I had, we were forced to act, but I don't think it encouraged me to do more of that later because it wasn't internally driven. Whereas setting the kids up for the invitation to action, I think, is a neat middle ground. Maybe if there's the space for action and it's still their choice to act, I think is how this becomes more meaningful and transferable to their lives later and makes it doable in our context. (Group 10, 9:34)

In this excerpt, Nicole, like the rest of the teachers, explained how action invitations are not only ‘doable’ in their context but also bring focus to developing student agency. The teachers felt that if students are given a choice, invitation, and support in acting, they can realize their potential to affect change and carry through their intentions. In so doing, they felt those actions became more 'meaningful and transferable.'

The teachers recognized the importance of shifting from being skeptical of promoting action with students to actively inviting students to it in certain contexts. It was far from their original stance in September 2020 and was facilitated, as described above, by successive examples and subsequent reflection on students' difficulty in following through with their intentions. The teachers realized that action at Cranberry High needed to be scaffolded. In contrast to September 2020, reflecting in February 2021:

(65) Mike: I would say for me, from the outside, probably the most profound shift in all of us, was our reluctance to carry out any Hodsonian sort of way of thinking with the kids. I think when we read Hodson in August, we were feeling; I’ve got no place for how I would be doing this.

Dave: Exactly, right?

Nicole: We were all like, whoa, whoa, whoa, whoa. Like red flag, no way. And I think now we're like, OK, no, we're not jumping in all the way, but we're going to get our feet wet in a way that's like OK for us and for the kids and this context. (Group 8, 55:21)

To summarize these insights and reflections, through the Learning study discourse, the teachers could consider collective action through the lens of teacher and student perspectives. Consequently, they became increasingly comfortable and open to scaffolding students' engagement with social action as an outcome of SRSE.

4.3.2 Dave and Nicole's Plans, Addressing SSI Topic Choice and Pedagogies Conducive to Action Taking

At the end of the Learning study, Nicole and Dave were formulating plans to provide action spaces and action invitations for their students in subsequent units (Excerpts 54 and 55). Important in these examples, and discussed throughout the Learning study about action-oriented SRSE, are pedagogical insights about SSI topic choice and pedagogies conducive to supporting action. From Excerpt 54, Dave has chosen the SSI (water quality). He has also indicated that engaging students in an inquiry project would be a suitable means to engage in action-oriented SRSE. Nicole is more ambiguous (Excerpt 55), privileging her students' choices as directives for the issue and the pedagogy of engagement.

Over the course of the Learning study, the teachers realized that the best SSI topic to promote action and who should pick it was a quagmire of considerations. In the Learning study, Nicole and Mike decided the topics for their students to engage with, the COVID-19 pandemic and climate change, respectively, while Dave let students choose. Focusing on the former, Mike felt that teacher-led topic choice set his students up well to engage in action because they all focused on the same area of climate change: "They know about what actions to take because of the whole Unit, right? It has been comprehensive. We've been doing this same topic since January, building to this, and it's what, February 23rd?" (Mike, ISM 13, 1:36). Speaking to student choice, Dave and Nicole note that disparate topics mean teacher support is likely to spread thin, which could translate to students' action potential. However, letting students choose garners more individual interest:

(66) **Interviewer:** The students chose the topic. Any benefits or drawbacks now that we've observed the lessons?

Dave: I think I wouldn't change it. There was a lot they had to know with all their different topics, and it was hard for me to support so many of them. But the boys who aren't maybe historically consistently engaged in their academics. The presentation had a lot of bumps, but they picked fishing because they fish with their parents. So cool, right? And you can see that in the Q&A. They hit it out of the park.

Nicole: Yeah, their presentation was wonky. But then the Q&A was so fluid. And this is exactly what we've been talking about connecting learning to students' backgrounds, having it be meaningful, they probably actually now have more information that they'll take back when they go fishing next time that maybe they share with parents or family. And so, I think that topic choice is big. And you scaffolded the topics. So, there's no unlimited topic choice. (Group 8, 41:02)

In the excerpt, Nicole and Dave privilege the lens into students' lives brought on by student topic choice. However, Nicole also alludes to a potential middle ground between student- or teacher-led topics found in Mike's 'Hope To' enactment. There, the SSI topic is dictated by the teacher – 'there's no unlimited topic choice' – thus supporting students with teacher knowledge of the topic. However, the actions themselves are student-led. This maintains student interest but positions teacher interest as a central consideration for which SSI topics are pursued. Mike reflects on the import of teacher interest in action-oriented SRSE in the final Group Meeting:

(67) Mike: I think you don't want to say, ‘I'm going to become an SRSE teacher,’ ‘I'm going to always start with issues...’ I think that's a very challenging way to go about it. I think you must be interested in it first and foremost. And then, if you are interested in it, you become more familiar with the story, the stakeholders, etc. And then you do, I think, the hard work, which is what we did this year, which is how the heck do you try to create an issues-based, scientifically rich conversation that leads students to care enough to act? (Group 10, 34:12)

From the teachers’ discussions, they agreed that teacher interest is an essential consideration for SSI topic choice. They felt that interest impacts the degree to which they might engage with the topic and the support they can provide students. However, not lost on the teachers was their school context. The teachers also felt that action-oriented science education was rare and ‘radical’ at Cranberry High. As such, should an issue want to be pursued in classroom spaces, they must advocate for that exploration.

Mike had a lens into this area in one of his research lessons. Most of his students participated in that class on a school silent day. The school’s Debate Club organized this day as a form of student activism. Students wrote an issue they cared about on a name tag and remained silent for the day out of solidarity with those affected. Topics included anti-Asian racism, Missing and Murdered Indigenous Women and Girls, and the Black Lives Matter movement. However, Mike noted that science-related issues were starkly lacking. Mike provides a reason for their absence following the lesson:

(68) Mike: You can see how there’s a certain sort of sway with areas of the school. There are activist pockets, and I think that most science teachers would feel that that’s certainly not the pocket to be in. (ISM 13, 8:25)

This excerpt exemplifies the feeling of the Learning study group. The teachers felt that although their students might demonstrate an interest in activism, the science context of their school does not. Consequently, they must condone and advocate that stance and the issues being addressed. For example, in the final interview and ISM 3, Nicole explained and demonstrated her preference for tackling the SSI of racist naming practices (Appendix J) or of gender disparities in science careers as a female engineer (Appendix K). For the teachers, important deliberations remained around which SSI topics should be brought into science class next year. However, they note that considerations are necessary and must include teacher interests and school norms.

Once a topic choice is deliberated, the teachers also wonder how to support students in acting. Mike wonders how best to support his 'Hope To' invitation in future years: "The project set them up so well for action, but there was still that hesitancy to do what they said" (Mike, Group 10, 1:16:08). Nicole also wonders how best to support her students' in consistently acting, ruminating on these topics throughout the latter half of the Learnings study (Excerpts 52 and 56).

Faye offers school-based areas to support action spaces that science teachers can leverage. She points to humanities teachers and school clubs as areas to draw inspiration or collaboration.

(69) **Faye:** So SRSE is a more radical approach, I would argue, for science teachers, whereas humanities teachers are further along that journey. They would have a lot to say about supporting and using SRSE. And then there's an invitation to action through our Model U.N. and Debate programs or maybe our Service Council or Student Council. So, there's sort of a further step that they can take there. Right now, we have a group of young students who come out of humanities discussions and are going to run an awareness of – it's a week to celebrate Asian culture in the city. But it's also to raise awareness of the shocking increase in this city, particularly against women, of Asian hate crimes. So that is going on. But we haven't been able to do that in the science world. (Int 2, 44:27)

This excerpt speaks to the potential of interdisciplinary projects for action-oriented SRSE as well as a recognition that there are different and capacious knowledge domains for the diverse set of pedagogies sought by the Learning study group. In this excerpt, Faye frames the context in which the teachers work as a resource to expand these knowledge domains and offers the insight that teachers need not know all of them because collaboration between *all* school-based individuals can provide a way forward. Given the time frame of the Learning study, it is unknown whether the teachers utilized these different school areas. However, through Faye's contribution, Dave, Mike, and Nicole were reminded that they can learn from the courses, clubs, and curricula that already do action projects and adapt that to their contexts.

4.3.3 Category #3 Summary

In Table 13, I give examples of the explanatory dimensions for the third category of description to summarize this section. This category presents how the teachers deliberated upon and enacted an SRSE approach that focused on promoting students' engagement with collective social action.

For the teachers, this approach to SRSE enables students to forward and enact collective actions on SSIs through the development of student agency. They sought to provide students with the action invitations, and action spaces they felt were required to enact this approach.

Table 13

Examples of explanatory dimensions for the third category of description.

Explanatory Dimensions	Category of Description 'Approach to SRSE'
	3. Promoting students' engagement with collective social action
Students' level of participation	*Collective social actions* considered as demonstrated by formulating plans to mitigate SSI-based harm.
Object for student development	*Student agency* by providing support, encouragement, and opportunity to build confidence in acting. Provided through action spaces (areas students can be supported in acting) and action invitations (introduction and encouragement to join action spaces).
Orientation to socioscientific issue engagement	Challenges: imposing action on students, deciding SSI topics, and exploring pedagogies conducive to action taking Strategies: *championing* action invitations, SSI topics, and leveraging other school areas.

Although deliberations were mostly conceptual, where only one teacher planned for and taught an action-oriented research lesson, through the Learning study discourse, the teachers were able to examine and shape their convictions of the importance of this critical aspect of learning through SSIs.

Careful reflections catalyzed the promotion of the shifts in their beliefs on the barriers to action their context provided. The participating teachers could examine and open their assumptions to the scrutiny of others throughout the Learning study. The teachers realized that if SSIs were to be acted upon in their context, they and their students needed to be advocates for that change.

They also drew from research lessons to consider how lessons could be oriented towards a more critical SRSE approach. This provided a concrete platform for them to think about how they might take specific steps to mitigate the challenges involved in this form of SRSE. These included exploring factors on which they should base SSI choice and exploring pedagogies conducive to action-taking. Consequently, the teachers were, minimally, able to come to *collectively* examine the possible inclusion of an approach to SRSE that aims at collective social action, albeit with varying degrees of conviction that this aspect is feasible or important to their classroom teaching.

4.4 Chapter Summary

This chapter presents three qualitatively different ways the teachers deliberated upon and enacted approaches to SRSE. Each approach is defined by how the teachers positioned students' level of participation (i.e., aiming at engaged critics, personal actions, and collective actions), which object of student development the teachers brought focus (i.e., cognition, beliefs, agency), and the teachers' orientations to SSI engagement (i.e., being a builder, negotiator, or advocate/champion). These show diverse ends and possible means of different SRSE approaches, all supported by the Learning study discourse. Key points embedded in each category relate to (1) how the approaches relate to the 3-VSL and what this relationship reveals about their possibilities, limitations, and connections; (2) what and how the Learning study discourse supported teachers in developing in their pursuit of SRSE; and (3) what design features and learning experiences the teachers employed in their varied SRSE approaches.

Chapter 5. Discussion

A tabular summary is consistent with phenomenographic approaches (e.g., Miechie et al., 2019; Tan & Caleon, 2022). For this work, Table 14 highlights the categories of description and their hierarchical order. The categories highlight three qualitatively different ways the teachers in this study understood and enacted SRSE. Category labels were constructed by paying attention to what the teachers focused on (Table 14, ‘explanatory dimensions’) and the meanings they ascribed to that focus (each category's column). The hierarchical order was constructed to illustrate how higher-ordered categories were more complex than others. Increasing complexity is reflected in the complexity of SSI engagement the teachers' provided their students and the teachers’ awareness of SRSE actants influencing their SRSE implementation.

Table 14

Categories of description and explanatory dimensions.

Research Questions	Explanatory Dimension	Categories of Description ‘Approaches to SRSE’		
		1. Developing a balanced stance to new socioscientific issue-related curricular initiatives	2. Promoting individual transformations through SRSE	3. Promoting students’ engagement with collective social actions
How SRSE was understood	Students’ level of participation	Engaged critics	Personal actions	Collective actions
	Object for student development	Cognitive and conceptual	Attitudes and beliefs	Student agency
Challenges arose and how they were addressed	Orientation to socioscientific issue engagement	Builder	Negotiator	Champion
Hierarchization of categories based on the complexity of socioscientific issue engagement and increasing awareness of SRSE actants		Increasing complexity of socioscientific issue engagement		
		Increasing awareness of SRSE actants		

In Category 1, the teachers focused on preparing students to be engaged critics of SSIs by developing their cognitive and conceptual knowledge related to each Vision of scientific literacy. The challenges they addressed were viewed as within their locus of control. This prompted the teachers to orient their engagement with SSIs as one that builds on prior knowledge and experience. In Category 2, the teachers focused on preparing students to forward personal actions on SSIs by developing their attitudes and beliefs. The challenges they addressed were viewed as both within and beyond their locus of control. This prompted the teachers to orient their engagement with SSIs as one that negotiates with others. In Category 3, the teachers focused on promoting students' engagement with collective social action. They intended for students to carry out proposed plans with others through the development of student agency. The challenges they addressed were viewed as interactions of internal and external factors. This prompted the teachers to orient their engagement with SSIs as one that champions a way forward.

If we take the educational utility of the categories (e.g., Marton & Booth, 1997) as oriented by the revised curriculum, Category 3 is preferred over Categories 1 and 2. It is explicitly geared toward supporting and achieving the Ministry of Education-mandated recommendations of enacting care-oriented, community-focused, and SSI-driven objectives and competencies (BCME, 2018a). With this orientation, complexity can be defined in how each category positions SSI engagement, coinciding to a greater extent with those ways of experiencing SRSE considered critical for the revised curriculum. Likewise, Category 1 and 2 can be defined as subsets of Category 3. For example, for students to engage in collective action that seeks to reduce harm produced by an SSI (Category 3), they must first have an awareness of the harm and how it is propagated (Category 1), develop their views and underlying positions (Category 2), and propose a way forward (Category 2). Complexity can also be defined as the teachers' increasing awareness of different actants influencing SRSE implementation. This complexity is discussed in Section 5.1.4.

The most complex category *differs* from the one which should always be encouraged. While promoting students' engagement with collective social action is the most complex category, or SRSE approach, in this analysis, it should not be pursued based on complexity alone. As Marton (1986) describes, this is only sometimes the purpose of mapping experiences in phenomenography. Mapping can also illuminate different experiences. The educational utility of these 'different experiences' can be derived based on context. As such, every category can have value based on teachers' preferences, the issue pursued, the students engaged, and the school inhabited. However, critical literacy (Vision III) aims are unique. These aims are some of the most difficult to enact in schools and some of the most worthwhile in responding to our world's perils. How teachers approach this aspect will draw attention in the remainder of this chapter.

In Section 5.1, I discuss the first guiding question through a theoretical focus. I discuss how each SRSE approach, which is each category of description (e.g., the balanced approach [Category 1], the transformative approach [Category 2], and the collective action approach [Category 3]), relate to the 3-VSL. In Section 5.2, I discuss the second and third guiding questions. I discuss how and what the Learning study approach provided teachers in their experiences of pursuing SRSE. These experiences advance three teacher attributes I deemed essential for SRSE development: (1) familiarity with the issue, (2) familiarity with pedagogies for issue engagement, and (3) teacher as learner. In Section 5.3, I return to the first guiding question and discuss it through a practical focus. I discuss what design features and learning experiences the teachers utilized in each SRSE approach and which features and experiences are missing to provide recommendations for future practice.

5.1 Approaches to SRSE in Relation to the Three Visions of Scientific Literacy

Each qualitatively different approach to SRSE contains theoretical perspectives forwarded by the 3-VSL. The Visions are conceptual literacy (Vision I), aimed at science's internal processes and products. Contextual literacy (Vision II) focuses on the relationships and impacts science has on society, and critical literacy (Vision III) targets science for actions and transformations. Each Vision was presented to the teachers to reflect on their past and current science teaching experiences and structure their understanding of SRSE. The theoretical perspectives focused on included (1) that the Visions represent a continuum of scientific literacy with different curricular emphases (presented in Figures 1 and 2) and (2) that multiple goals for Vision III are possible (presented in Figures 3 and 4).

As explained in Section 3.6, to connect each SRSE approach to the 3-VSL, the teachers' research lessons and related teaching experiences were mapped in Figure 3. This also shows how each enactment of SRSE is related to the STSE, Socioscientific Issue-based, STEPWISE, and Critical Pedagogy of Place frameworks reviewed in Chapter 2. Each approach to SRSE will be iteratively overlaid in Figure 3 to structure the discussion. The lack of axis arrows is intentional. The subsequent figures imply no correct 'outcomes'; they are a tool to think about Vision III enactments for this discussion. Pedagogical insights and personal reflections the teachers considered will be forwarded at the end of this section. This alludes to the relationships between approaches and the teachers' deliberative steps to gain new understandings.

5.1.1 The Balanced Approach

In the balanced approach (Category #1), the teachers gave equal consideration to all three Visions of 3-VSL. Dave, Nicole, and Mike planned for their students to learn the concepts behind (Vision I), the context around (Vision II), and the harm caused (Vision III) by select SSIs. Conceptual literacy was deemed a crucial understanding for general science education. It also provided a backbone for SSI-specific contextual and critical literacy development. Contextual literacy was essential to understand the scientific enterprise's impact on society and vice versa concerning the issue. Critical literacy was important to *recognize* and *evaluate* some of the harms caused by the issue. This is shown in Figure 7 on the horizontal axis. In addition, each teacher's lessons inhabited the full range of the vertical axis.[5]

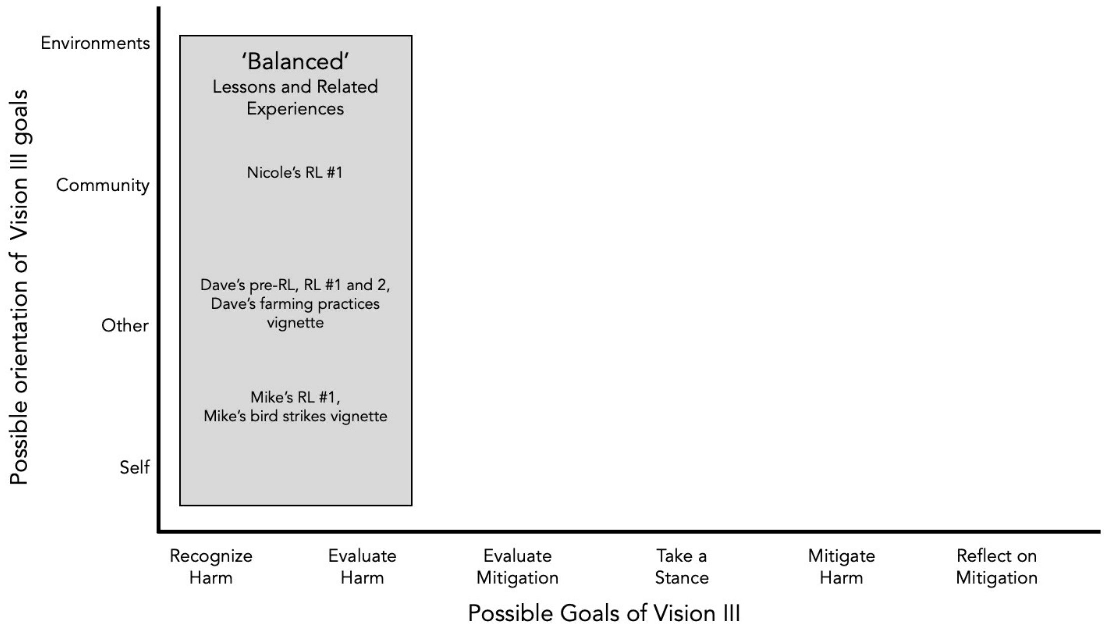
For the teachers, the focus on each Vision of the 3-VSL was meant to develop the conceptual and cognitive processes they felt students required to be engaged critics of SSIs. The teachers sought to build students' critical knowledge based on the typical goals of Vision I and II. Whether Nicole was ensuring thoughtful comments could be made by students about the trade-offs pandemic control measures (Section 4.1.1, Nicole's RL #1) or Mike was brainstorming with students critical questions they should consider for climate change stakeholders (Section 4.1.2, Mike's RL #1), ensuring students could thoroughly critique an SSI as backed by scientific evidence was the prime intent of SRSE in this category (Excerpts 4, 5, 6).

This intent of SRSE echoes Sjöström et al.'s (2017) assertion that the 'critical' in critical scientific literacy includes "both an awareness and critical stance" (p. 182) towards risks associated with the products of science and technology. This recognizes one's need to be aware of harm before addressing it. While containing two components on the horizontal axis of Figure 7, the teachers' perceptions of the balanced approach to SRSE fall somewhere between Vision II and Vision III. It is Vision II in that the teachers focused on the usefulness and meaningfulness of science in preparing students for life beyond school (e.g., decision-making, critical questioning). It is Vision III in that the teachers focused on the 'awareness' side of critical literacy as forward by Sjöström et al. (2017).

[5] In Figure 7, 'RL' refers to research lessons and their number in the teaching sequence. Vignettes are teaching experiences Dave, Mike, and Nicole felt were related to the Leaning study but not directly captured in research lessons or with formal observations. For example, the 'China Plague' vignette, mentioned in Chapter 4 and Appendix J, represents an experience Nicole felt she was engaging in SRSE. As will be shown, that experience was aimed at developing students' attitudes and beliefs towards the impacts of disease etymology (e.g., consider the 'Spanish Influenza' or 'gay-related immune deficiency' as an early term for acquired immune deficiency syndrome or AIDS [Ayala & Spieldenner, 2021; Wood, 1991]).

Figure 7

Teachers' research lessons and related experiences mapped onto a conceptual tool visualizing the diversity of Vision III goals, adapted from Hodson (2011) and the British Columbia Science Curriculum (BCME, 2018a, 2018b). The 'Balanced' approach is Category 1 from the phenomenographic analysis. RL is research lessons. Vignettes are teaching experiences the teachers felt were related to the Learning study, but not directly captured in research lessons or with formal observations.



For example, through evaluating SSIs, the teachers' guided their students to become aware of various SSI stakeholders. Recall the articles Nicole's students read in her first research lesson (Section 4.1.1) or the discussion connecting the cultural zeitgeist to the racist views of eminent scholars in Dave's pre-research lesson (Section 4.1.2). These practices align with the Vision II-oriented sociocultural current of STSE (Pedretti & Nazir, 2011; Ziman, 1994). They show students that science and technology exist within a broader sociocultural context. However, when coupled with the harm caused by an SSI – from the above examples, the differential effects of COVID-19 restrictions and cancel culture in scientific discovery, respectively – this approach to SRSE also highlights how the sociocultural context, of which the students and teachers are part, can be seen as “liable for creating” (Lee et al., 2013, p. 2103) those very issues. This positioning of SRSE bridges the Vision II and Vision III categories. It highlights their supportive and connected nature (Sjöström et al., 2017).

The adoption of the balanced approach mirrors research showing science teachers are willing to use science education as a means to prepare students for life beyond school but remain hesitant to fully explore other Vision III formulations (Bencze, 2017; Pedretti & Bellomo, 2013; Sadler et al., 2006; Tidemand & Nielson, 2017). Indeed, preparing students to be engaged critics is perhaps a kinder formulation of preparing 'armchair critics' (Hodson, 2011), wherein individuals can critique an issue but are more content talking about it than doing something meaningful. Proponents of Vision III see this as a problem. Given current environmental and societal pressures, compelling cases are made for more active, political, and activist science education, as forwarded in Chapter 2. That said, for Dave, Mike and Nicole, the balanced approach to SRSE was still valuable for students (Section 4.1) *and* served as a fertile base for exploring additional SRSE approaches. The latter point will be discussed in Section 5.1.4.

5.1.2 The Transformative Approach

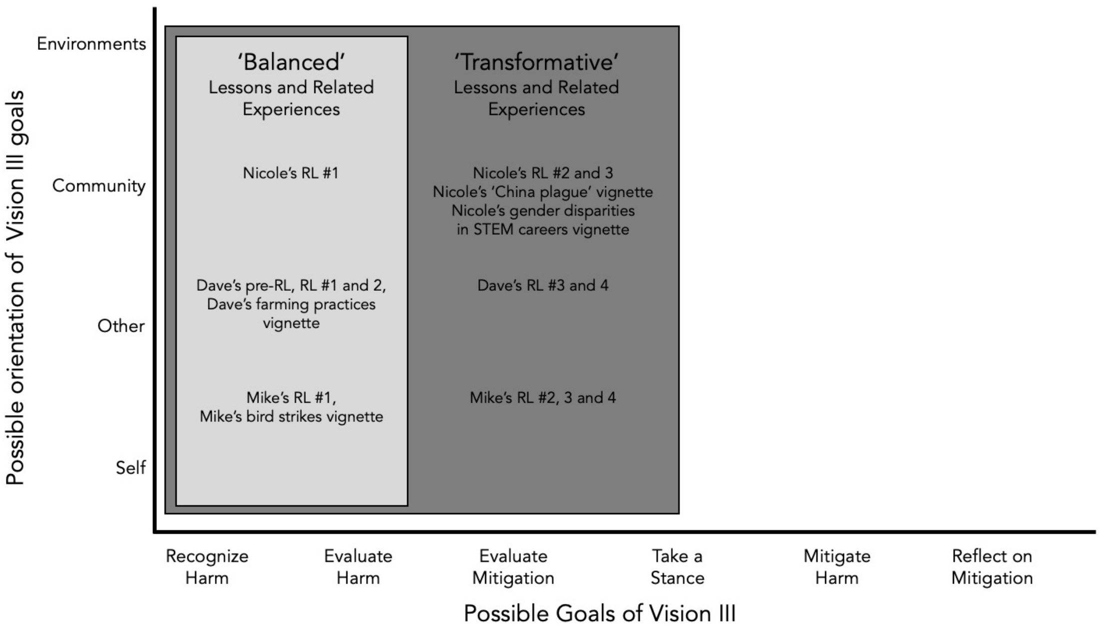
In the transformative SRSE approach (Category #2), Dave, Nicole, and Mike sought to develop their students' attitudes and beliefs towards SSIs through the transaction of ideas and engaging students in metacognitive practices. Examples include Nicole having her students reflect on the consequences of calling COVID-19 the 'China Plague’ (Appendix J) or Dave promoting his students to reflect on their life histories before considering others’ views of SSIs (Section 4.2.2). The teachers then prompted this attitude and belief development to be used by students for personal actions. Contra the balanced approach, which assumed students would use their developed thought space to do something in the future, this approach expected a proposal to be made. From Nicole's conversation, the proposal was to not use the term 'China Plague.'

The Vision III goals in the transformative approach to SRSE included two additional points from the horizontal axis of Figure 8. The teachers had students *evaluate different SSI mitigation strategies* and encouraged them to *take a stance* on what to do next. This SRSE enactment is like the Socioscientific Issues-based framework or the values-driven current of STSE (Pedretti & Nazir, 2011; Sadler, 2011). They prioritize the enhancement of ethical reasoning, character formation, and moral development through the transaction of ideas.

The transformative SRSE approach also shares components of the STSE socio-ecojustice current. There, formulaic and prescriptive actions are to be avoided (Hart et al.,1999). Student actions are meant to empower democratic choices. Keeping this ethos, there are no ‘correct’ actions – developing action plans, changing personal habits, and educating others is as acceptable as lobbying power brokers or raising funds. In fact, these former actions were precisely the types taken or proposed by students through each of the teachers’ classes. As the students chose “an appropriate and justifiable course” (Hodson, 2011, p. xi), they acted in ways the socio-ecojustice current would advocate. Diverse and personal, these actions uphold Pedretti and Nazir’s (2011) suggestion that educators must take care in navigating “the fine line between indoctrination and empowerment” (p. 618). Actions chosen by students in the transformative approach upheld their right to self-determination while the teachers tempered any adherence to a dominant framework or goal (e.g., other steps toward socio-political action).

Figure 8

Teachers' research lessons and related experiences mapped onto a conceptual tool visualizing the diversity of Vision III goals, adapted from Hodson (2011) and the British Columbia Science Curriculum (BCME, 2018a, 2018b). The 'Transformative' approach is Category 2 from the phenomenographic analysis. RL is research lessons. Vignettes are teaching experiences the teachers felt were related to the Learning study, but not directly captured in research lessons or with formal observations.



Though aligning with the socio-ecojustice current, students' actions stopped short of directly mitigating harm from an SSI (see Section 4.3.1 and Excerpts 59, 60, and 61). Taking a justifiable stance and proposing what to do next is unlikely to address SSI-based harms fully (Bencze, 2017; Hodson, 2011; Dos Santos, 2009), notwithstanding the effects sharing proposals may have on others. If a goal is to use science education for social reconstruction, the socio-political dimensions of action– actions which impact people, corporations, and systems – must be included (Amos et al., 2020). That said, in not mitigating harm from an SSI, students' action proposals still showcase some nuances and educational benefits of dwelling on specific points of Figure 8's horizontal axis (highlighted in Section 5.3.1).

First, this upholds students' right to self-determination (Bencze, 2020). Culminating SRSE instruction by taking a stance on an SSI mitigation strategy, regardless of if it's enacted, holds to the suggestion that students proceed to the level "appropriate to the topic in hand, the learning opportunities it presents and the stage of intellectual and emotional development of the students" (Hodson, 2003, p. 658). Second, like the balanced approach, the teachers saw value in developing students' attitudes and beliefs (Section 4.2). SSIs are not monolithic. In some cases, changing views and intentions towards them might be all that is feasible or desirable in a particular context (see Section 5.2.1.4.). However, for SSIs in which action *was* feasible, desirable, and even planned for, every socioscientific mitigation strategy Dave, Mike, and Nicole facilitated students in forwarding was rarely, if ever, realized. This experience pushed the teachers to reconsider Hodson's (2014) warning. If one does not teach students how to act, in their context, action is unlikely to occur. This produced two lines of thought.

The first was reflective. The teachers recognized that this stance sharply contrasted their views about student action compared to the beginning of the Learning study (recall socially *irresponsible* science education from Section 4.3.1). The second was pragmatic. The teachers felt that if students would not be translating their intentions into actions, especially after so much time and planning was dedicated to their design, students deserved further support. It, therefore, became necessary for Mike, Nicole, and Dave to focus on developing student agency as a catalyst to act out intentions, and to do so in groups to develop that agency further. This treats students' developed attitudes and beliefs as pathways to socio-political resolutions.

5.1.3 The Collective Action Approach

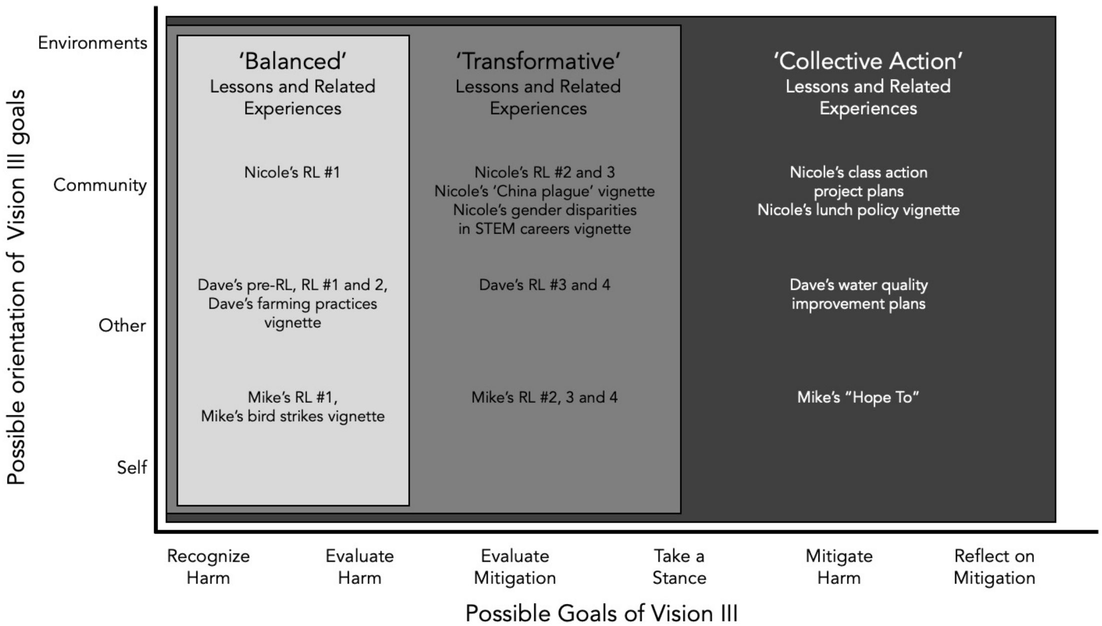
In the collective action approach to SRSE Dave, Nicole, and Mike sought to develop their students' agency so they might turn any pro-environmental or other socio-ecojust mindsets into actions. Tangible examples include Mike providing his students with a 'Hope To' invitation (Excerpt 57), Nicole formulating plans for a whole class action project (Excerpt 56) and Dave thinking of ways to invite his Chemistry 11 class to conduct a water quality project (Excerpt 55).

Importantly, how best to support student action resulted in action invitations, as described in Chapter 4. The teachers had several interacting internal and external pedagogical and personally reflective considerations (see Section 4.3.1), which resulted in them choosing a middle ground between 'no action' and 'imposing action.' Indeed, imposing action (e.g., through projects that culminate in research-informed and negotiated action [Krstovic, 2017]) was still being debated by the teachers in the Learning study (e.g., Excerpt 64). Action invitations were a middle ground to develop student agency while maintaining student autonomy.

The Vision III goals in the collective action approach to SRSE included two additional points from the horizontal axis in Figure 9. In all examples, students were or would be invited to *mitigate the harm* caused by an SSI and prompted to *reflect on that mitigation.* This SRSE approach is like the Critical Pedagogy of Place and STEPWISE frameworks (Bencze, 2017; Gruenewald, 2003). They prioritize students' active contributions to the well-being of individuals, societies, and environments through varied socio-political endeavours. Providing action invitations also moves past the STSE socio-ecojustice currents formulation of action – in the collective action approach, certain actions may indeed be more desirable than others based on impact.

Figure 9

Teachers' research lessons and related experiences mapped onto a conceptual tool visualizing the diversity of Vision III goals, adapted from Hodson (2011) and the British Columbia Science Curriculum (BCME, 2018a, 2018b). The 'Collective Action' approach is Category 3 from the phenomenographic analysis. RL is research lessons. Vignettes are teaching experiences the teachers felt were related to the Learning study, but not directly captured in research lessons or with formal observations.



However, these actions still rely on the teacher providing and the student taking steps toward them. In this sense, the armchair critic (Hodson, 2011) critique still looms. If invitations are provided, and no student takes them, what then? How might invitations be made more enticing and meaningful? This point will be picked up in Chapter 6.

Regardless of whether students take the invitation, the teachers found they must provide it first. As presented in Chapter 4 (Excerpt 63), Dave noted that in May of 2021, the teachers sought areas in the curriculum to invoke this stance. This budding disposition toward viewing the curriculum as an invitation to engage students in collective action moves past a passive interaction with scientific principles, social dimensions, and ethical dilemmas, where the positioning of students is based primarily on a duty of care perspective. From a duty of care lens, teachers focus more on students' cognitive and emotional outcomes, where they may never ask students to act out their intentions: “that's irresponsible” (Mike, Int 1, 1:00:20).

An active disposition involves teachers consciously being a lever for change for what the class community feels is right, also focusing on supporting behavioural outcomes. From a lever for change lens, there is recognition that students want to solve compelling issues and that it is all right for teachers to seek the same. Likewise, there is no longer the assumption that students can resolve issues without practice, guidance, and scaffolding. As Hodson (2011) notes, “one of the best ways of learning to address SSIs is by addressing SSIs” (p. x).

5.1.4 Deliberative Steps Within and Between SRSE Approaches

Mike, Dave, and Nicole engaged in deliberative steps to overcome challenges they perceived to influence each of the three SRSE approaches. In Chapter 4, these were labelled pedagogical insights and personal reflections (the last rows of Tables 7 through 13). They are important because they support each teacher’s SRSE enactments. However, they also laid a necessary foundation for additional exploration. Each can be thought of as steppingstones for diverse SRSE uptake. In relation to the phenomenographic analysis, the deliberative steps explicate the active framing of each category and the relationships between them. They provide tentative evidence regarding the ‘nature’ of SRSE learning (e.g., Tan & Nashon, 2013).

The central pedagogical insight for the balanced SRSE approach (Category 1) was the teachers exploring ways to deal with their perceived lack of SSI-specific content knowledge. They overcame this challenge by posturing a learner’s deposition in self, adopting a mindset of curiosity to expand their understanding. The primary personal reflection was around how to deal with the power differentials found in student-teacher relationships when talking about values, overcome by realizing values are always present and, therefore, must be critiqued.

These insights and reflections are primarily within teachers' locus of control. They arose from teachers' self-assessments. Also, they did not directly brush against other educators, parents, or school community members. As a mainly accepted approach, 'balanced' SRSE provided the teachers with a base to develop additional insights and reflections to support other SRSE approaches.

For example, the main pedagogical insight in Category 2 (transformative) centred around the teachers' finding ways to support students' SSI-related skills and exploring pedagogies conducive to developing attitudes and beliefs. These were overcome by negotiating and scaffolding students' skills and negotiating from others' practices. The main personal reflection was around how best to engage with their school context given the SRSE approach desired. This was overcome through supported and negotiated implementation.

The insights and reflections of the transformative approach are within and beyond teachers' locus of control. They arose from the teachers' context and directly brushed against other educators, parents, and school community members. However, to develop them, the teachers directly pulled from the insights and reflections gleaned from the balanced approach (e.g., teachers' stances on how to talk about values are required to interact with the demands of their school context and negotiate SRSE implementation). Hence, by developing insights and reflections from one approach to SRSE, the teachers were supported in developing more.

This idea continues to the third SRSE approach. The collective action approach to SRSE (Category 3) had different but related insights and reflections to the transformative (Category 2) and balanced (Category 1) SRSE approaches. The main pedagogical insight for collective action was the teachers' exploring factors on which they should base SSI choice and exploring action-oriented pedagogies to best support students. The former was addressed through SSI topic deliberation, and the latter by leveraging other areas of the school. The main personal reflection was whether the teachers should impose action, addressed with action invitations.

Like above, to develop the collective action insights and reflections, the teachers directly pulled from the insights and reflections gleaned from the balanced and transformative approach. For example, the balanced approach (Category 1) included teachers' specific knowledge domains and feelings about utilizing positions of power, the transformative approach (Category 2) included the students, teachers, and the broader school context in which SRSE would be implemented, and the collective action approach (Category 3) combined these internal and external insights and reflections, forming new actants requiring attention (e.g., the assemblage of teacher, student, and school-based positions driving SSI topic choice). These new actants gave way to further pedagogical insights and personal reflections (e.g., to deliberate SSI topic choice).

Viewed as a whole, these connected deliberative steps contribute to an expanding network of pro-SRSE strategies and actants (i.e., what Bencze [2020], borrowing from Actor-Network-Theory [Latour, 2005], would call a 'dispositif' [Foucault, 2008]). For each of the three approaches – balanced, transformative, collective action – as pedagogical insights were gleaned and personal reflections developed, the Learning study group witnessed the extension of the assemblage of mostly cooperating actants in new and expanding directions.

For the teachers, these connected insights and reflections allowed them to champion practices which moved outside the confines of the context in which they teach. In this sense, the collective action approach, like the transformative and balanced approaches above, may provide a base to sort through and develop additional insights and reflections to explore other SRSE approaches. In this way, each approach to SRSE can be seen as means towards SRSE construed more broadly rather than terminal ends. These different means, as investigated, may provide additional examples of insights and reflections teachers lean on as they not only resided within but considered and developed other approaches to SRSE. These successive deliberative steps indicate potential aspects embedded in the nature of SRSE learning (implications addressed in Chapter 6).

5.2 The Learning Study Developing Essential Teacher Attributes

The deliberative steps described delineate characteristics the teachers developed during the three SRSE approaches, which the Learning study model supported. These characteristics overlap and strengthen. They are shared by teachers engaging in similar practices that prioritize science education for social responsibility (e.g., Aikenhead, 2022; Bencze, 2017; Herman et al., 2018; Hodson, 2013; Mansour, 2010; Sadler, 2011; Smith & Sobel, 2014). To map these characteristics, I adapted Presley et al.'s (2013) and Herman et al.'s (2018) teacher attributes for Socioscientific Issues-based instruction using pooled results from each SRSE approach. They include (1) familiarity with the issue, (2) familiarity with pedagogies for issue engagement, and (3) teacher as learner. In discussing the attributes, I will highlight learning and teaching experiences from the Learning study that supported each attribute's development.

5.2.1 Familiarity with the Issue

The first attribute of importance was teachers' familiarity with the issue. From Category 1 (balanced approach), the teachers needed knowledge about the scientific concepts, social context, and harm caused by specific SSIs. From Category 2 (transformative) and 3 (collective action), they required knowledge related to the opinions and beliefs of various SSI stakeholders and what action pathways students could take to address those issues. Finally, the teachers needed knowledge of the school's position on the issue, so students' engagement with them could be efficaciously supported (e.g., Mishler, 1986). The permutations of this attribute used to organize this section include:

a. Knowledge about the scientific content of the issue.
    i. Issue-based nature of science understanding.
b. Awareness of social considerations of the issue.
c. Awareness of action pathways to address the issue.
d. Awareness of the school's position on the issue.

5.2.1.1 Knowledge About the Scientific Content of the Issue. Scientific content knowledge of the issue is vital because SSI exploration typically resides in science class (Lee & Witz, 2009). In this study, this knowledge was the base for all future instruction. That said, it's likely impossible to provide students with all scientific knowledge of an issue and unfeasible to expect a teacher to do the same. Moreover, much conceptual knowledge about SSIs may be undiscovered or in the making. It is, therefore, essential to equip students with an understanding of how to appraise scientific knowledge, including how it is generated, reviewed, and the degree to which it can be relied on to inform future choices.

This knowledge falls under Nature of Science understanding (Hodson & Wong, 2017; Kolstø, 2001; Lederman et al., 2002). As will be shown (Section 5.3.2), no teachers in this study were observed explicitly teaching about the onto-epistemic features of science. They chose instead to focus on issue-specific knowledge in the research lessons.

The concurrent-and-successive Learning study model might have hindered the growth of issue-specific knowledge because of the different objects of learning. Learning study research indicates that as science teachers construct an object of learning, their perceived gaps in knowledge can be addressed (Holmqvist & Olander, 2017; Olander & Olander, 2013; Nilsson, 2014; Vikström, 2014). However, the studies above relied on variation theory to explore the object of learning, where teachers decided upon which critical aspects are important. In this study, 3-VSL did not require such deliberation. As such, teachers may have missed opportunities to explore the scientific content knowledge of the issue they deemed important.

A potential trade-off arises between a deeper understanding of issue-specific scientific content knowledge and other important aspects the concurrent-and-successive model provides (e.g., sharing issue-specific pedagogies). In response, online or hybrid modalities of Learning study could be leveraged. They can share knowledge about objects of learning related to similar SSIs between schools (Calleja & Camilleri, 2021), with university partners (Koutsouris et al., 2017), or internationally (Isoda et al., 2017). Nature of Science knowledge can be included to address any perceived lack of scientific content knowledge. All suggestions help Learning study members add scope to their research lessons (e.g., Holmqvist & Olander, 2017) and address the challenges of science-in-the-making many SSIs represent (Hodson, 2020).

5.2.1.2 Awareness of Social Considerations of the Issue. Successful instruction about an issue also depends on teachers' awareness of the issue's social (including ethical), technological, and environmental considerations (Barrett & Nieswandt, 2010; Hodson, 2011). One way to develop this awareness is found in Nicole and Mike's experiences of teaching SRSE. In many of their SRSE experiences, they focused on diverting attention away from the knowledge-as-product stance science teachers oft project and protect (Pedretti & Nazir, 2015), utilizing knowledge-as-process instead. In other words, Nicole and Mike relied on their ability to find more information (e.g., through primary/secondary research) rather than always 'providing' that information outright (Excerpts 11 and 12). This allowed them to explore with students issue-specific social considerations while still being guided by some awareness of what those considerations might be.

Here, the concurrent-and-successive Learning study model helped the teachers because they could discuss social considerations embedded within the diverse SSIs they were exploring. The model allowed for deep contextual insights across multiple topics regarding what social considerations could be pursued and where more information could be sought. In Nicole's classes, the differential effects of COVID-19 control measures on populations of lower socioeconomic status were pulled on by Mike. In his classes on climate change, socioeconomic status was an important discussion point for some students concerning who might bear the brunt of climate distress. Mike's students focused on those impacts in terms of a country's Gross Domestic Product. Nicole's students looked at the earnings of multiple communities. Though different issues and a different framing of ‘wealth,’ the social consideration remained similar and thus transferable between their research lessons.

The transference of effective teaching practices and ideas is facilitated in science Learning studies by collaboration and the discourse in meetings (Holmqvist & Olander, 2017; Olander & Olander, 2013). Teachers learn from each other new ways to interpret curriculum (Tan & Nashon, 2015), structure their lessons (Nilsson & Vikström, 2015), and learn more about concepts of interest (Attorps & Kellner, 2017). However, allowing that knowledge to be further contextualized to teachers' experience, as Mike did with Nicole's ideas, should remain a focus. As Nilsson and Vikström (2015) demonstrate, "teachers do not simply receive knowledge that others create to teach but produce knowledge for teaching through their own experiences" (p. 2854). This production of knowledge should be cultivated (Kincheloe & Steinberg, 1999).

5.2.1.3 Awareness of Action Pathways to Address the Issue. Also needed is action pathway knowledge, including those of direct (e.g., recycling, tree planting) and indirect (e.g., organizing petitions, lobbying power brokers) actions. Teachers' knowledge of action significantly influences students' action potential (Huffing et al., 2017). If a goal is for students to address an issue, methods should be provided. In the present Learning study, planned actions were of a direct nature. Dave could pinpoint the usefulness of water quality data in informing government agencies about a problem when discussing the design of his Chemistry 11 project (Excerpt 55). However, how that information could inform policy was never forwarded. Here, Dave had some action pathway knowledge he could leverage as a source for students to build from. However, too targeted a focus on direct action can draw focus away from the corporations, governments, and policies responsible for those issues on a larger scale. Teachers must also be aware of indirect action confronting SSI-based harm's systemic causes and mechanisms (Bencze, 2020; Steffen et al., 2018).

In these instances, a Learning study's facilitator or knowledgeable others could be leveraged. In Tan et al.'s (2019b) neuroscience-framed Learning study, one of the facilitators was a neuroscientist (Y.S.M. Tan, personal communication, November 18, 2021). This provided a boon for the participants as the nuances and intricacies of brain science research could be explained. This highlights the potential for several knowledgeable others to enter the Learning study discourse. One could imagine presentations by subject-specific experts – in this context around political action or student activism – as ways group members could explore select theoretical knowledge or better understand elements of an object of learning. Future research in this arena would be of interest, especially as more expansive objects of learning are pursued (e.g., Pang, 2010, 2019).

Without such initiatives, facilitators of action-oriented Learning studies could draw from McClaren and Hammond's (2005) three ways to learn in the action sphere, including learning about, through, and from action. All learnings are meant to provide experience for pupils to eventually pursue these areas themselves. Derr (2020) forwards that teachers can take a similar progression in their own exploration. This recommendation echoes the one earlier regarding social considerations of an issue: learning alongside students is a way to develop knowledge domains. Another option the teachers in this study brought forward was to leverage other areas of the school already engaged in action projects (Excerpt 69). Here, the broader school community becomes an additional knowledgeable other to support Learning study practices.

These points highlight the benefits of online Learning study models between schools, districts, or countries (Hrastinski, 2021). Though action pathways will differ in specificity, consistent considerations, like the ones forwarded about social considerations (Section 5.2.1.2), are likely. In the interior of BC, hydroponic gardens run by schools and students have become popular to combat climate change and the community's food security (Leader, 2021). The action pathway here could be school action bettering community issues. This provides a 'win-win' for many of the actants involved, and similar lessons could be transferred to different contexts via online and hybrid Learning studies. In transferring action pathways to other contexts, it is crucial for teachers to "produce knowledge for teaching through their own experiences" (Nilsson & Visktröm, 2015, p. 2854). As found in this study, the context in which an action pathway is to be pursued must be carefully considered.

5.2.1.4 Awareness of the School's Position on the Issue. Another issue familiarity aspect in this study came from the teachers' awareness of the school's position. Co-worker, administrative, parental, and student support impact science education practices (Pedretti et al., 2008; Mansour, 2010). It follows that if controversial issues are to be introduced, let alone acted on, a 'lay of the land' is needed. This can aid teachers in prudently aligning assemblages of actants (see Section 5.1.4) to further their classroom interests.

In this study, several SSIs were forwarded when SRSE was first introduced. The topic of Henrietta Lacks and racialized practices of cancer research was the most controversial, as seen by the teachers. On one side was the recent international attention to 'radicalized practices' given the murder of George Floyd (e.g., Boudreau et al., 2021; Green, 2021). This made the issue – well-known for centuries (Watson et al., 2018) – take on a specific spotlight, which made the teachers understandably hesitant to approach it. The hesitancy brought on by international attention was compounded by the teacher's knowledge of the issue. They felt they were lacking in all three domains already mentioned. However, another reason radicalized practices of cancer research were considered controversial was given what the school science context typically condoned. As described in Chapter 4, science at Cranberry High was traditional, inviting little controversy and preferring to remain apolitical.

Mike's research lessons provide an example. One coincided with a day organized by the school's Debate Club as a form of student activism (Section 4.3.2), termed 'silent day.' Students wrote an issue they cared about on a name tag and remained silent for the day out of solidarity with those affected. Following, Mike noted that not a single SSI appeared even though all problems presented were significant (e.g., Missing and Murdered Indigenous Women and Girls).

The student's name tags demonstrate those issues' inclusion and acceptance in some facets of the school. They could also allude to the hesitancy or neglect of those issues in science learning contexts. In each of the teachers' research lessons, the teachers led the goal of exploring and addressing issues. It was only in Mike's classes on climate change that students appeared ready to engage without significant teacher direction and input. This could be due to the prominence of climate change in news media or students' familiarity with the issue. However, from a school-wide perspective, the relative acceptance of climate change as an issue worth addressing might also derive from the confluence of scientific evidence and contextual zeitgeist.

Climate change has significant scientific backing, thereby being seen as 'belonging' in science class. It typically[6] stokes little controversy for student and teacher engagement. In addition, action on climate change aligns with the norms of Cranberry High. There is a long tradition of environmental clubs and school gardening as means to explore climate change, often led by science department members. Taking a step back, this places action on climate change as an apolitical topic, already subsumed in the dominant ideology of the context (Ruitenberg, 2009).

On another extreme, racist science practices, as exemplified by Henrietta Lacks, while having strong scientific evidence (Allchin, 2021; Watson et al., 2018), do not have a history of science class engagement at Cranberry High, despite its history in other school-based subjects. This positions action on racist science practices as controversial in science learning contexts. Taking a step back, this places action on racist science practices as political, not matching the dominant ideology of the school context.

Following suggestions by Roth (2010), this apolitical vs political orientation toward an issue – based on the degree to which it 'belongs' in science learning contexts – positions racist

[6] The word typically is used here to recognize that climate change can indeed be a controversial topic depending on the context in which it is explored (e.g., Monroe et al., 2021). Here, the focus remains on Cranberry High.

science practices as requiring 'activity' or 'activism' – "contributing to the production and transformation of society broadly" (p. 283) – while climate change invites 'action' – doing some tasks. To be sure, actions flow into activity and should be organized around it. However, the point is whether the school community *views* that action as part of a more extensive activity.

This demonstrates a differential politicization of specific issues in the school based on prior course-based engagement and what the knowledge of that discipline values. Climate change can be interpreted as an apolitical entity in science class because it flows from traditional science knowledge and has a history in the science classroom. Racist science practices can be interpreted as political entities in science classes because of their perceived departure from traditional science knowledge and the lack of historical engagement. Though apolitical orientations still contain political dimensions of the dominant ideology, to further socioscientific inclusion along the discussion mentioned, questions remain regarding issues' political or apolitical nature and their inclusion/exclusion in varied classroom contexts. Educators may need to be supported in either turning issues from political to perceived as apolitical to foster action or turning all apolitical orientations into political ones with the goal of activity (or activism).

Alternatively, the above discussion on action and activism was predicated on the assumption that *action* on an issue – now broadly defined – was a desirable way forward (e.g., Hodson, 2011). However, there is value in *each* SRSE approach, and they must be employed based on student, teacher, and context. Of the two examples in this section, it might well be more accessible for students and teachers to devise action on climate change than trying to tackle systemic racism. For the latter, the end goal may be an increased sensitivity towards the issue (e.g., Category 2). While a teacher might engage students in how this has personal implications and potential for individual actions, the students might also (especially at higher grade levels) need to recognize systemic racism as something more extensive; and perhaps more extensive than what an individual or group of teachers could tackle in their classroom at a particular moment, particularly when this form of science education is relatively unfamiliar to both teachers and students. This is where the categories described in Section 5.1 become essential. While Category 3 might best reflect the kinds of approaches teachers might work towards for certain SSIs, the second approach (Category 2) or even the first (Category 1) might suffice contingent on the affordances of the classroom (e.g., time, maturity of the students, and initial familiarity of the issue). In this sense, educators need to be supported in *differentiating* SSIs – their nature as given by specific contexts and the kinds of action desirable and prudent – and the kinds of discourse that could best engage pupils.

This discussion culminates with the idea that teachers should lead by example regardless of the SRSE approach. They need to condone an issue's inclusion in the first place with the aim of students engaging with it in diverse ways. As seen with Dave, this can still include students' choice of the issue. It is the fact that the issue is being included at all that matters.

To bring an issue into the curriculum, teachers need awareness of the school's position to move forward effectively. Key questions can be asked, adopted from Hodson (2020), to aid in this process: What issues are absent in my science classroom? What is the underlying rationale for these choices? Who are the stakeholders? What constitutes their interests? Whose voices are privileged, and whose are marginalized? Who benefits? Who is harmed? Does inclusion promote the common good and well-being? Should I support it? Answering these questions might lead to the inclusion or exclusion of specific issues based on teacher-student-school negotiations. But the idea remains that students are likely to mirror the issues condoned by their context, and teachers' awareness of what is or is not acceptable provides insights for expanded engagement.

5.2.2 Familiarity with Pedagogies for Issue Engagement

Issue-specific knowledge is necessary but not sufficient for full SRSE engagement. 'What' to teach differs from 'how,' and the teachers in this study also felt it was important to have familiarity with pedagogies for issue engagement to support students. This is the second teacher attribute of importance. The permutations of this attribute used to organize this section include:

a. Awareness of general pedagogies for engagement.
b. Knowledge of students' skills and readiness for different types of engagement.
c. Awareness of the school's position on pedagogies for engagement.

5.2.2.1 Awareness of General Pedagogies for Engagement. The pedagogical knowledge for SSI engagement includes approaches which might be foreign to science teachers (Aikenhead, 2006; Pedretti & Nazir, 2015). To propel Vision I, II, and III understandings anchored by an issue, students should engage in several areas (e.g., Table 1). Notably, most practices turn the objective, teacher-centred, and didactic pedagogies of 'typical' science classes (often the signature pedagogies for science [Shulman, 2005]) into ones focused on creative, affective, moral, critical, and place-based approaches. Owing to the practice's departure from typical science classes, the teachers in this study, like elsewhere (e.g., Bencze, 2017; Gray & Bryce, 2006), felt they needed awareness of different methods to engage students. In short, the teachers were challenged to move past their comfort zones.

In all the teacher's research lessons, a new pedagogical tool or idea drew their deliberations. Importantly, the Learning study group provided guidance "on how to approach day-to-day teaching" (Gray & Bryce, 2006, p. 184). They promoted greater awareness of pedagogies for issue engagement (e.g., Excerpts 36, 37, 38). The transference of effective teaching practices and ideas is facilitated in Learning study by collaboration and the discourse in meetings (Olander & Olander, 2013; Tan & Nashon, 2015; Vikström, 2014). Attorps and Kellner's (2017) study echoes this point. There, nine teachers of Grades 1 to 6 engaged in a variation theory-framed Learning study. Some senior grade teachers would share with the junior grade teachers what could be 'best' for photosynthesis instruction over a year. Upon trying these ideas, the junior-grade teachers found they successfully taught photosynthesis.

In the present study, Mike, Dave, and Nicole gleaned a general awareness of pedagogies for issue engagement from each other and, through collaboration and reflection, the potential and limitations of each. Online or hybrid models of Learning study can support this type of collaboration. Aside from talking to other educators (Fullan, 2011; Lefstein et al., 2020; Nelson et al. 2010), Suh et al. (2021) and Wadjaja et al.'s (2021) studies have shown the potential of watching other Lesson study groups' research lessons (a variant of Learning study). This observation successfully facilitated new pedagogical ideas between contexts and, in the context of an SRSE Learning study, could be used to further teachers' familiarity with pedagogies for issue engagement from a 'day-to-day' teaching perspective.

5.2.2.2 Knowledge of Students' Skills and Readiness for Different Types of Engagement. For pedagogical knowledge to turn into pedagogical-content knowledge, understanding the context in which the pedagogies are employed is needed (Cochran et al., 1993). This includes a knowledge of the students the teacher will engage with and their skills and readiness for new teaching methods. As found in this study, the skills of students based on past science education experiences resulted in barriers to some SRSE engagement.

This information was primarily found with pre-lesson surveys. Recall Dave's students being able to give only minimal social implications of an SSI (Excerpt 31). However, Dave was initially prompted to question his students in this area because Nicole's students lacked an 'outward lens' to other social considerations regarding COVID-19 (Excerpt 30). This back-and-forth of exploring students' skills and readiness and proposing ways forward was significant for each SRSE approach (see Excerpts 32, 33, and 34). This is a common finding in science education Learning studies (Nilsson & Vikström, 2015; Nilsson, 2014) – this is why pre-tests are so valuable (Vikström, 2014). However, the inter-grade nature of the 'back-and-forth-ness' deserves attention. It was facilitated by the type of collaboration embedded in the concurrent-and-successive model. It allowed insights into students' skills across grades to be explored.

This finding is echoed in Attorps & Kellner's (2017) study. There, Grade 1 through Grade 6 teachers reflected on what prior knowledge students would need to engage with photosynthesis. They pinpointed the insufficient knowledge to certain grade bands through pre-tests. This allowed the teachers to create a scope and sequence of learning activities based on absent knowledge. Though not a concurrent-and-successive model, the idea of investigating pupils' school-wide knowledge, skill, and experiences to be aware of students' readiness concerning select research lessons remains. This, in turn, can capture how different populations of pupils' view subjects as a whole. In the present study, Nicole reflected that science education at Cranberry High was primarily oriented towards "memorize and do a test" (Int 2, 5:05). By looking across grade levels through the concurrent-and-successive model, the teachers were provided with evidence of this claim, but more importantly, ways to creatively and iteratively move past it (recall the deliberative steps from Section 5.1.4).

5.2.2.3 Awareness of the School's Position on Pedagogies for Engagement. Another teacher attribute is an awareness of the school's position on pedagogies for issue engagement. To some degree, the issue chosen to engage with will influence the pedagogies pursued (e.g., Levison, 2010). A robust testing culture can preclude open-ended inquiry based on assessment mandates (Tidemand & Nielson, 2017). Adherence to traditional ideals of science education can stifle SRSE efforts. As described, when science education is oriented towards 'memorize and test,' teachers that go against the grain –including debates, socio-political action, value-driven discussions, etc. – may bring about questioning from colleagues and parents. These are non-trivial pressures (Bencze et al., 2006; Can et al., 2017) – many of which Dave brought up throughout the Learning study (Excerpt 44) – and the restrictive culture of science departments in schools have been well documented (Aikenhead, 2006). Knowing the 'lay of the land' regarding accepted pedagogies is important.

Given the dearth of teachers' entering the science teaching profession globally (Gore et al., 2018; Gist et al., 2019; Han et al., 2018), and the fact that many prospective science teachers want to join the profession to engage in practices directly related to SRSE (Fuchs et al., 2022), this area can be further framed as retention and recruitment issue. How can science teaching cultures be more accepting of diverse teaching practices? Learning study, as demonstrated, provides a way forward for those engaged in the professional development approach (Section 5.1.4). But in this study, convictions were bolstered more than changes in culture.

At the end of the Learning study, Dave still noted that doing SRSE was like "swimming into a massive river upstream" (Int 2, 37:33). The issues chosen and the pedagogies employed remained a quagmire of considerations. While knowing the school's position on these issues might not turn the tide of the river, it can minimally provide educators with the knowledge to better their upstream swim; and perhaps, as shared and justified, gain colleagues along the way.

5.2.3 Teacher as Learner

Another attribute the teachers displayed in all approaches to SRSE was their disposition as a learner. Though discussed explicitly in Category 1 (balanced), the teacher as learner attribute permeates all categories: it facilitated the exploration of new knowledge, beliefs, and pedagogies for all SRSE approaches. The permutations of this attribute used to organize this section include:

a. Honest about knowledge and pedagogical limitations.
b. Flexibility to position self as knowledge facilitator and/or authoritative contributor.
c. Willingness to negotiate with different perspectives.

5.2.3.1 Honest About Knowledge and Pedagogical Limitations. As a learner, the teachers recognized their knowledge and pedagogical limitations, being honest about their inexperience with certain issues and ways to engage students. The teachers were also open about their hesitancy in Vision III orientations. The teachers' honesty about these areas facilitated deeper and authentic conversations, clarifying and expanding their beliefs about what science education is and means (e.g., Section 5.1.4. as the teachers shifted their characterization of SRSE away from socially *irresponsible* science education). As found in several science teacher Learning studies, teachers' understanding and articulation of perceived limitations are often a precursor to learning and positive change (Holmqvist & Olander, 2017; Olander & Olander, 2013; Tan & Nashon, 2013; Vikström, 2014).

Pedagogical honesty is essential to foster changes in instruction, but personal honesty about values and positions may also be necessary. Recall Dave and Mike's conversation about

Mike's attendance at a climate march (Excerpt 18). Mike was adamant that since he did not tell his students he was going, he would not influence students. Dave pointed out that Mike's attendance at the march would make his values known regardless of intent, causing an influence on students. Over successive meetings, Mike eventually felt that “we are living out our values. And I think that we don't have to run from that" (Group 8, 51:57). This level of personal reflection aided Mike in being more forward about his positions on SSIs. Also, it is a representation of honesty. It highlights perceived growth from a perceived limitation.

Mike being more comfortable forwarding his positions on issues is essential in SRSE. Extant literature highlights the importance of dissecting, articulating, and championing personal positions on issues in effective Vision III-oriented SSI-based instruction (Dos Santos, 2009; Hodson, 2011, 2020; Lee & Witz, 2009; Morales-Doyle, 2017). That said, the ‘growth' attribute is also crucial. Vis-a-vis the previous point, this has the potential to develop SRSE approaches further. As such, in addition to the Learning study supporting honesty about knowledge and pedagogical limitations, it might also, with topics in which values are a large part, facilitate honesty about values.

Following the progression of other Learning studies (Holmqvist & Olander, 2017; Olander & Olander, 2013; Tan & Nashon, 2013; Vikström, 2014), this might likewise provide a springboard to learning and positive change. That said, teacher 'values' are a messy construct (Pajares, 1992). It would be premature to suppose individuals’ honesty about them is required for all SRSE approaches. As an example, when does belief turn to value? Are the axiological nuances of teachers' ideas to be separated from onto-epistemological ones, or would it be better to assume values will 'follow' pedagogical reflection (Fenstermacher, 1979; Pajares, 1992)? Important questions remain around the role of values in Learning studies oriented toward SRSE.

5.2.3.2 Flexibility to Position Self as Knowledge Facilitator and/or Authoritative Contributor. As learners, the teachers also positioned themselves as knowledge facilitators instead of authoritative contributors. A knowledge facilitator involves a willingness to learn with and from other actants in an educational space. An authoritative contributor is a determiner of 'right' and 'wrong' while encouraging diverse views to be shared (Herman et al., 2018). The importance of being a knowledge facilitator is common in science education literature (Aiknhead, 2006; Sadler, 2011). However, the ways the teachers in this study employed it deserves attention. They positioned themselves as knowledge contributors with their students and with each other and the theoretical perspectives of the Learning study.

5.2.3.2.1 Knowledge Contributors with Each Other and Theoretical Perspectives. With each other, the teachers' disposition as knowledge facilitators helped them display attributes common and desirable to fruitful professional communities (Avidov-Ungar & Konkes Ben Zion, 2019; Lewis et al., 2009). They constantly offered new ideas, were excited to learn alongside their colleagues, displayed critical but collegial questioning of beliefs and practices, and maintained high standards and motivation to improve student learning (Attorps & Kellner, 2017; Huang et al., 2021). They also maintained this stance with the theoretical perspectives of the Learning study. The 3-VSL was not seen as the sole authority to guide SRSE instruction, dictating science education's 'correct' aims or requiring specific pedagogies for engagement. Instead, it was viewed by the teachers as a symbolic entity (actant) aligned with the teachers in pursuit of implementing curriculum reform. In other words, the theoretical framework was part of the expanding SRSE dispositif (e.g., Bencze, 2020), as mentioned in Section 5.1.4.

The 3-VSL was integral to the teachers' identifying and seeking out the previously mentioned knowledge domains (Section 5.2.1). It acted as a catalyst for exploration and reflection, becoming what Vikström (2014) calls a "lived theory " (p. 716) or a natural part of the Learning study discourse. The 3-VSL was a sense-making and articulation tool for the teachers' curricular insights (Excerpts 9, 10, 40, 41, 48), prompting them to "word [their] world" (Iftody, 2013, p. 393) as the 3-VSL was critiqued and adapted to their context. As such, it and the teachers acted as knowledge facilitators to each other. The 3-VSL had many teachers' capabilities for engaging with SRSE: a capacity to contribute ideas and to be changed in the process.

From theoretical perspectives contributing ideas to teachers, Tan's (2017, 2014a) and others (Nilsson & Vikström, 2015; Vikström, 2014) work provides evidence. In these studies, framing teachers' Learning study discourse using a theoretical perspective expanded the group's collective wisdom, showing new ideas and goals for science education and ways to achieve them. In Tan's (2014a) study, the teachers developed a deeper understanding of how variation theory perspectives can be infused to enhance teaching practices to better student learning.

Echoing this finding, Nicole and Dave felt the 3-VSL was a valuable tool to reflect on their practice and what they were trying to get their students to learn. They relayed how they would look at their lessons or assignments and consider where the conceptual focus was, where the contextual lies, and where the critical could draw greater attention (Excerpts 10, 41, and 49). In each case, they were thinking of places the different Visions could be incorporated, which they felt prompted them to reflect on their practice more, and by extension, better their student's learning. 3-VSL gave them a vocabulary to think more extensively about their practice.

From the view of the teachers contributing ideas to the theoretical perspectives, the group's discourse in Group Meeting 9 provides evidence (in addition to other areas [e.g., Excerpt 9]). Though not the intent given the theoretical perspectives presented, in most research lessons, the teachers guided their students in a very general fashion from Vision I to II to III perspectives.

This might be a fault of how the 3-VSL was initially presented: as a stepwise continuum of science education foci – though Sjöström et al. (2017) do note that many Visions can be employed at the same or different times. Regardless, in Group Meeting 9, Dave and Mike discussed the 3-VSL being visualized as a three-part Venn diagram rather than a linear continuum (as presented to the teachers through Figure 2) (Excerpt 40). The idea is that the confluence of all three Visions simultaneously could be a teaching priority. In this example, the Learning study members bridged their knowledge of the 3-VSL, gleaned in the Learning study, and sought ways to apply it in novel situations. This is an example of bridging a theory-practice gap (Nuthall, 2004) or 'praxis' in a Learning study, as described by Wood et al. (2015).

These examples show evidence of a dialectic relationship between teacher knowledge and theoretical knowledge (Tan, 2019a). Both are positioned as knowledge facilitators, actants capable of learning in an educational space. The group not only learned new ideas and goals for science education and ways to achieve them but, in the process, altered their ideas of the initial approach to the Visions altogether. The Learning study group theorized (i.e., contributed ideas to the theoretical perspective based on their context) different ways the 3-VSL could be presented visually to extend and better their practice.

Importantly, this dialectic relationship between teacher knowledge and theoretical perspectives gives rise to the Stenhousian notion of principles of procedure. As Vikström (2014) notes, future research is needed to judge the validity of claims made from a Learning study. For example, inquiries could evaluate whether the linear or three-part Venn diagram of 3-VSL improves student learning in novel situations. If so, Learning studies might provide teachers opportunities to contribute to the science education literature other teachers find helpful, that, as tested, contributes to the "science of teaching" (Elliot, 2012). This 'testing' of principles of procedure can be facilitated by online and hybrid models of Learning study. Cross-school, district, and national insights about different or same theories and different or same topics can be contrasted, iterated, and delineated based on areas in which their application is most meaningful (e.g., Calleja & Camilleri, 2021; Hrastinski, 2021).

5.2.3.2.2 With Students. For students, the role of knowledge facilitator or authoritative contributor was greyer. Teachers acting as learners alongside students makes sense, given the vast knowledge needed to engage with SRSE. However, the degree to which a teacher should be a facilitator as opposed to an authoritative contributor was found to vary based on the classroom contexts of this study. For example, learning science with students can be necessary for dealing with science-in-the-making. But a time will likely come when the teacher is needed as an authority on a topic, say, in the form of direct instruction, when it is desirable in terms of time spent and ease of understanding to communicate to the students the ‘correct’ answer or process to follow (e.g., Bencze & Alsop, 2009). This was common in the opening portions of each teacher’s research lessons.

Likewise, when discussing different positions on an issue, there is the risk of relativism, where any idea is acceptable if it is someone’s opinion (e.g., Excerpt 17). Being a knowledge facilitator on equal footing with the student's present problems here. First, it can ignore the reality that certain positions are not of equal merit, robbing students of the potential to develop the critical skills necessary to judge the worth of different positions. Second, it diminishes the teacher's position as a guide and mentor. In these scenarios, the teacher must be willing to invite multiple positions on an issue (e.g., for fluoride in drinking water, against fluoride in drinking water, fluoride for only 12-year-olds and under, etc.) and be equally prepared to “identify, clarify, and challenge the assumptions” (Hodson, 2020, p. 606) of those positions. Teachers must remain flexible with their roles as knowledge facilitators vs authoritative contributors, recognizing situations where their authority is needed and suitable to support student learning.

5.2.3.3 Willingness to negotiate with different perspectives. Another attribute of teachers as learners displayed by Learning study members was their willingness to negotiate different perspectives. In science teaching and learning literature, there are well-documented examples of traditional views barring novel and often research-aligned perspectives (e.g., Can et al., 2017; Macleod, 2014). However, lamenting limitations does little for student learning; the path forward must be rooted in turning limitations into opportunities.

Mike's comment after a recent staff meeting provides an example. He respected all staff members' viewpoints but still pushed for a broader awareness of what could be possible (i.e., more than one ‘pillar’) (Excerpt 48). Dave moved forward with SRSE in the AP curriculum in ways that still recognized the final exam's importance – something important to the school community (Section 4.2.2). Dave saw the benefits for student engagement and skills development SRSE could provide but nonetheless felt those skills alone would not do justice to the scope of the exam. Dave held both positions in tension throughout the Learning study.

In both examples, Dave and Mike recognized the need for more diversity in science education practices at their school. They slowly pursued these areas while being mindful of the expectations and norms of their community. They positioned their work not as confrontational or antithetical to current practices but one which built on its success and ameliorated some of its problems. This included faithfully meeting curricular competencies, evoking the school's mission statement in all classrooms, and fostering diverse student engagement. Turning limitations into an opportunity through negotiation allowed the teachers to slowly shift the needle for their school community regarding what science could be and could mean. These practices are akin to

Vesilind and Jones (1998) ‘change through a sideways door’ (p. 766) approach, where educators implementing new curricula act as ‘test cases,’ rather than overt, and sometimes domineering, critics. Here, classroom practice, as enacted, justified, analyzed, and shared, serves as invitations to new science teaching and learning ideas.

5.3 Design Features and Learning Experiences of SRSE Lessons

Each qualitatively different approach to SRSE shared design and learning features with the STSE socio-ecojustice, Socioscientific Issues-based, Critical Pedagogy of Place and STEPWISE frameworks. Design features refer to broader characteristics incorporated in the design, development, and implementation of learning experiences (e.g., basing SRSE lessons around an SSI). Learning experiences overlap with design features and represent opportunities students have to engage in particular types of learning (e.g., engaging with multiple SSI perspectives) (Presley et al., 2013). A summary of each, organized by framework, is found in Chapter 2, Table 1. I will first discuss similarities, followed by differences.

5.3.1 Similarities

Across the approaches to SRSE, all lessons shared the design feature of basing lessons around a compelling issue (Pedretti & Nazir, 2011; Presley et al., 2013; Sadler, 2011; Zimmerman & Weible, 2017). They were the organizing features found in the teachers’ objects of learning: pandemics, emergent research in land and water use, and carbon emissions. Likewise, stakeholder or networked analysis of the issue concerning social, political, economic, environmental, etc., were included. This practice is standard across the frameworks, but STEPWISE advocates for a specific tool – actor-network maps, based on Actor Network Theory (Latour, 2005). The actor-network maps are meant to highlight to students the various living, non-living, and symbolic actants that may influence the creation and propulsion of specific issues and the connections among those actants (Bencze & Krstovic, 2017). Dave and Mike explored this broadly through ‘buckets’ students could base their conversation on (e.g., environment, social, economic, political). Nicole utilized a ‘future web’ to showcase the relations (explained in Section 4.2). In Nicole’s research lessons, students mapped the perturbations of school closure from pandemic restrictions to food loss for those pupils enrolled in lunch assistance programs. This allowed for a rich examination of the trade-offs between certain pandemic-based choices. Nicole’s students were then able to identify the importance of following school-based restrictions so that case counts could remain low, the schools would remain open, and lunches would be provided. Agreeing with Bencze (2017), using specific networking tools can support students’ analysis of SSIs, their consequences, and the stakeholders most liable or affected by them.

Across the approaches to SRSE, all lessons also shared the design feature of basing instruction around an apprenticeship or scaffolded model of ‘teacher teachers’ and ‘student’s practice’ (Bencze, 2017; Presley, 2013). This model is explicitly advocated by the STEPWISE and Socioscientific Issued-based frameworks but not found in the STSE socio-ecojustice current or Critical Pedagogy of Place. In the latter two, ‘student teaches’ or ‘teacher learns with students’ could be equally likely (e.g., Pedretti & Nazir, 2011). The scaffolded model assumes teachers are needed to fill in gaps in student knowledge which students demonstrate back through practice.

In the present study, all lessons had elements of ‘teacher teaches.’ Nicole, Dave and Mike either shared important conceptual, contextual, or critical knowledge, modelled certain skills, or scaffolded students’ engagement with higher-order practices. The lessons also had ample areas for student practice, typically geared towards their culminating experiences (e.g., Nicole’s class discussion and Mike and Dave’s projects). Focusing on teacher teaches, Mike had nine pre-research lessons on climate change-specific Vision I and II understandings he felt students needed to know to engage in the rest of his unit. On the recommendation of the Learning study group, Dave dedicated an entire modelling lesson to foreground students' projects, showcasing how ethical implications could be explicitly connected to scientific concepts.

Alternatives to these curricular flows could be starting lessons with class discussions or focused reflections on students' past experiences. Students could then teach each other, analyzing and synthesizing information from curated articles or videos. However, none of the teachers in this study preferred to design the research lessons that way. This could be due to the signature pedagogies of teachers' past science experiences impacting their current practice. All the teachers indicated they were taught science from a Vision I perspective, typically with lectures and worksheets. Their familiarity with these 'ways' of learning science could result in a familiar and preferred way to teach, especially when approaching novel areas.

The point is not which way is better. STEPWISE includes a teacher teaches component based primarily on pragmatism and a pedagogical flow most familiar to science teachers (Benzce, 2017). In this way, STEPWISE endeavours to 'meet teachers where they are at,' catering to the comfort science teachers often have of 'filling students' knowledge gaps,' giving a mini-lecture, etc. (Sadler et al., 2006) before moving to other, less familiar areas (e.g., ethical considerations through networked analysis) (Bencze, 2017). Future teacher development programs may follow suit, using teachers' idiosyncratic tendencies for instruction, once explained and justified, as a base for more exploration (e.g., Lee & Witz, 2009). This could give teacher-learners a sense in which contexts 'teacher teaches' or 'student teaches,' 'teacher doesn't teach,' or 'community member teaches,' etc., is preferable.

Learning experiences provided to students across the SRSE approaches included many forwarded by the Socioscientific Issues-based framework, STSE, STEPWISE, and Critical

Pedagogy of Place (Herman et al., 2018; Krstovic, 2017; Steele, 2014; Zimmerman & Weible, 2017). Students had opportunities to engage with scientific ideas and theories related to the issue being considered through direct instruction or secondary research. For example, Dave had his students read scientific articles for the Research Café. He made the distillation and connection of the articles to the AP curriculum a central component of students' projects.

These experiences were seen as central to supporting the 'beautiful structure' of science education at Cranberry High (Excerpt 48) and to base future coursework around (e.g., Nicole used R_o values as a base for students to think about seating restrictions in their lunchroom). Like several Socioscientific Issues-based and Critical Pedagogy of Place studies focused on science education (Chung et al., 2016, p. 8; Lee et al., 2013, p. 2088 class 1 and 2; Zimmerman & Wible, 2017), scientific ideas and theories remain central and indispensable components to engage in subsequent activities, and, more plainly, be part of *science* class.

Learning experiences also provided to students included negotiating social and ethical issues. As alluded to with the 'future webs,' this was often done following some networked or stakeholder analysis. Aside from Nicole's students' example of the loss of lunch assistance programs, Mike encouraged his students to engage in thoughtful discussions on individual flight restrictions to curb climate change (Section 4.2.2). Who should be targeted? Who should be allowed more flights? Should countries with populations least responsible for climate change be spared? Conversations of similar tones were held in Dave's classes.

Importantly, through these conversations, students were also engaged in higher-order practices – like reasoning, argumentation, critical thinking, and position-taking – which are learning experiences advocated across the STSE, STEPWISE, Critical Pedagogy of Place and Socioscientific Issues-based frameworks. Sadler et al. (2007) and Kinslow et al. (2018) subsume some of these higher-order practices under 'socioscientific reasoning skills.' A broad measure that "describes thinking practices that individuals use as they make sense of, consider solutions for, and work to resolve complex SSI" (Romine et al., 2017, p. 276). Research shows that the results of this development include increasing students' ability to value and relay other individuals' perspectives (Chung et al., 2016), increasing students' compassion for those affected by select SSIs (Lee et al., 2013), and developing students' understandings of the tentative nature of scientific knowledge production (Kinslow et al., 2018). In the present study, Nicole noted students' increased compassion for those affected by COVID-19, echoing Lee et al. (2013) (Excerpt 25). Mike felt his students' communication skills were exemplary (Section 4.2.2), and they could articulate various ideas from multiple perspectives (Chung et al., 2016). Regardless of student outcome, these learnings minimally point to the favourable potential of engaging students in higher-order practices around SSIs of interest.

5.3.2 Differences

Across the SRSE approaches, differences in design features and learning experiences were also apparent. One central design feature missing from the SRSE approaches included students' taking action to address the issue under consideration (Bencze, 2017; Pedretti, 1997; Roth & Lee, 2004). Forwarded by the STSE socio-ecojustice current, Critical Pedagogy of Place, and STEPWISE, personal actions like developing action plans and sharing those with others were found in the second approach to SRSE (Category 2, Transformative). The more socio-political and collective actions were forwarded, though not realized, in the third approach (Category 3, Collective Action). This area was discussed in Section 5.1.

Learning experiences forwarded by the frameworks not included in any enactments of SRSE included the Nature of Science themes associated with the issue under investigation

(Karisan & Zeidler, 2014; Herman et al., 2018) and engaging students in inquiry projects (Pedretti, 1997; Zimmerman & Weible, 2017). Both learning experiences are often heralded as central components of science education, encompassing learning about science and doing science, respectively (Hodson, 2003). Their omission from each SRSE approach is noteworthy.

Nature of Science themes are numerous and debated (Abd-El-Khalick et al., 1998; Hodson & Wong, 2017; Lederman, 2007). Their nuances will not be redrawn here. Generally, Nature of Science themes are associated with the epistemic characteristics of science (Lederman et al., 2002; McComas et al., 2000). For example, "scientific knowledge is tentative; empirical; theory laden; partly the product of human inference, imagination, and creativity; and socially and culturally embedded" (Hodson & Wong, 2017, p. 6).

Several authors argue that the best way to teach Nature of Science themes is explicitly (Abd-El Khalick & Lederman, 2000a, 2000b; Kampourakis, 2016; Khishfe & Lederman, 2006) where themes are touched upon as they come up in instruction. For example, highlighting funding models of scientific research and the problematic influences of people and corporations on science and technology products (Bencze, 2020) could be used to discuss the socially and culturally embedded aspects of scientific knowledge. An implicit approach assumes students will automatically learn Nature of Science themes due to studying science (Abd-El Khalick & Lederman, 2000a). In this study, the teachers appear to have taken the implicit route.

Nature of Science themes are evident in Nicole's lessons, where the science behind COVID-19 restrictions was discussed. This science-in-the-making provides evidence of the tentative Nature of Science, as discoveries shifted local regulations and mandates almost weekly. Mike's lessons on tackling and unpacking climate change highlighted the empirical nature of scientific knowledge and, importantly, the need for that knowledge to be peer-reviewed and replicable. Given the pockets of climate change denial in climate change spaces, these ideas are central. Finally, Dave's lesson on the tragedy of the Tragedy of the Commons was rife with the socially embedded theme as the nuances of the period in which the Tragedy of the Commons was developed were put in relation to the predominant racist ideologies of the Jim Crow Era policies and discourse. In each example, Nature of Science themes could have been explicitly explored, perhaps resulting in different lesson foci and outcomes. Nicole's students might have suggested weekly changes to school policy based on evolving evidence; Mike's classes could have utilized peer review of their culminating projects to explore the notion of replicability further; Dave's classes could have included explicit discussion of the current period and how that might affect the research articles explored in the Research Café.

Though possible, the question is whether the changed lesson foci would be desirable. The answer necessarily depends on the purpose of the lesson. Thinking back to each teacher's object of learning, Nature of Science themes might have led students to appropriate them more effectively. But this was not what drew each teacher's focus. As illustrated in Chapter 4, the teachers were already exploring new pedagogies, concepts, and theories in personal and challenging ways. The teachers' focus on these aspects of their pedagogy necessarily drew focus away from *all* potential learning experiences that could have been added to their lessons.

A point which bears highlighting, these foci represent a benefit of the Learning study approach: the freedom teachers have in expressing their ideocratic knowledge and choosing how to approach their classrooms. As such, the omission of Nature of Science themes, which some argue needs to be addressed (e.g., Karisan & Zeidler, 2017), becomes a point of future research. For example, Akerson et al. (2017) used a Lesson study to develop pre-service science teachers' pedagogical content knowledge for teaching Nature of Science. Holmqvist & Olander (2017) used a variation theory-framed Learning study to pursue similar ends with seven secondary school teachers. Future Learning studies can draw inspiration from these results. They could explore how the addition of different theories shapes meetings discourse or what a focus on objects of learning directed to varying themes within the Nature of Science might add to our understanding of Nature of Science teaching and learning and Learning study more generally.

In addition to the absence of Nature of Science themes, the teachers did not pursue inquiry projects. On a broad level, inquiry projects are instances where learners develop questions, seek information to explore those questions, analyze, evaluate, and interpret the information, propose answers, explanations, or predictions, and communicate the results (NRC, 1996). Inquiry projects have several formulations, typically based on the role of the teacher and student in the inquiry process (Bybee, 2006; Grady, 2010). For example, Grady (2010) provides an inquiry matrix based on the degree to which a teacher or student leads different parts. A student may be given a question to answer by a teacher, guided to plan their methods and let alone to interpret the results. Alternatively, students may develop their own questions and methods but be guided in results interpretation. The teacher is a consultant, resource, mentor, and guide in both formulations. As defined by Grady (2010), inquiry projects are often scaffolded. The teacher sets boundaries, but what occurs therein is quite open.

Regardless of student- or teacher-leading degree, inquiry projects are common in SSI-based teaching (Pedretti, 1997; Zimmerman & Weible, 2017). Reasons are numerous, including inquiries close connections to the scientific process (Fuchs, 2013; NRC, 1996; Pedretti, 1997), national and provincial standards (Bybee, 2006), the natural inclusion of Nature of Science themes (Lederman et al., 2014), and pathways towards decision-making or action (Bencze, 2017; Levinson, 2018b; Roth & Lee, 2004). Indeed, in the context of this study, leveraging inquiry projects would have likely invited several learning experiences and design features notably absent from the SRSE approaches described in Chapter 4. There is ample evidence that inquiry projects can, at the same time, introduce fundamental Nature of Science themes and lead to student action (e.g., in the form of Research-informed and Negotiated Action projects [Hoeg et al., 2015; Ramjewan et al., 2017] or through socio-scientific inquiry-based learning [Levinson, 2018b]).

Like the Nature of Science discussion above, the omission of inquiry projects provides ground for discussion and future research. First, the time frame of the Learning study could have precluded inquiry project inclusion. The progression of learning experiences included in the SRSE lessons was a considerable commitment for the teachers, given their reduced class time brought on by COVID-19 and the scope of the Learning study research lessons. There were frequent moments when the teachers were crafting their objects of learning where they commented on the brevity of the research lessons and how that dictated what could be possible. Full student-led inquiry projects were felt to take a unit to develop wholly, and the research lessons were pitched at a series of classes at most. This points to the need for more extended Learning study formulations encapsulating more classes if inquiry is to be pursued.

Second, engaging in inquiry around an issue often ends by advocating a point of what to do next. This is part of 'communicating results' usually found in the implications section of quality research (e.g., Arsenault, 1987; Clarke, 1998; Fuller et al., 2023; Gentles et al., 2021; Jedrzejko et al., 2021; Jedrzejko et al., 2022; Lee & Morimoto, 2021; Molyneux et al., 2022; Sue-Chue-Lam et al., 2022; Tsang et al., 2021). Levinson (2018b) describes this process as 'ask, find out, act' in the socio-scientific inquiry-based learning framework. A student might explore how to resolve fuel conservation at their school (ask), seeking out areas uncharacteristically cold in the winter and devising experiments to reduce energy flow (find out). These results are then presented to ameliorate the initial issue, presenting the findings of the experiments as recommendations to the school council (act).

In this example, starting an inquiry project and reaching its conclusion vis-a-vis Levinson (2018b) provides a path to consider each level of student participation found in Categories 1 through 3. ‘Ask’ mirrors the engaged critic, ‘find out’ alludes to processes which inform personal actions, and ‘act’ are collective actions realized. However, these various levels of student participation, as forwarded in Chapter 4, were wrought by contextual considerations as the teachers tried extending, questioning, or moving past their context's dominant science education ideology. Moving through these tensions captures the whole experience of the teachers enacting SRSE. This entire experience underscores many teachers’ hesitancy to engage in inquiry projects. In other words, it makes sense to avoid SRSE inquiry projects initially because of the number of unknowns and tensions within them. It takes a capable and confident teacher to undertake an SRSE inquiry project successfully within school contexts.

Nonetheless, at the end of the Learning study, the teachers were pursuing inquiry ideas in future SRSE planning (e.g., Dave’s water quality project). From these results, it appears that once teachers had implemented their initial set of learning experiences – based on whatever they deemed necessary and meaningful – they were primed to include more. This incremental progression to learning experiences not initially included in SRSE instruction is an exciting area of future research. What would inquiry-based SRSE look like? What different learning experiences and design features should be broadly included with SRSE practices? Such questions require prolonged investigations and more teacher freedom regarding the scope of their projects.

5.4 Chapter Summary

In Section 5.1, I discussed the value the teachers placed on each SRSE enactment and how dwelling within one approach served as a base to develop pedagogical insights and personal reflections to explore other approaches. I argued that these insights and reflections represent 'deliberative steps' that delineate means towards SRSE construed more broadly, in its varied potential forms, rather than terminal ends. This discussion provides recommendations on supporting and moving between SRSE approaches. In Section 5.2, I discussed the learning and classroom experiences the teachers engaged in that the Learning study model provided. I argued that these experiences advanced three teacher attributes essential for SRSE development: (1) familiarity with the issue, (2) familiarity with pedagogies for issue engagement, and (3) teacher as learner. This discussion foreshadows future professional development and teacher education goals. In Section 5.3, I discussed what design features and learning experiences the teachers utilized in each approach to SRSE and which were missing to provide recommendations for future practice. The discussion highlighted the idiosyncratic tendencies of science teachers toward certain design features and learning experiences. I argued that these should be fostered for further SRSE exploration. The discussion of how the teachers enacted and viewed SRSE and how and what they developed professionally, as supported by the discourse of the Learning study, draws implications. These are covered in Chapter 6, including limitations and delimitations of the work.

Chapter 6. Conclusions, Limitations and Delimitations, Significance, and Implications

This chapter presents the research conclusions, along with limitations and delimitations. The chapter concludes with discussions of significance, implications, and future research.

6.1 Conclusions

A Learning study as a teacher professional development approach was employed to study and support teachers' exploration of Socially Responsible Science Education or SRSE against the backdrop of curriculum reform. Working with three teachers and one administrator in a high school setting in the province of British Columbia (BC), Canada, one overarching research question drove this study: **How did high school science teachers participating in a Three Vision Scientific Literacy (3-VSL)-framed Learning study understand and enact SRSE**? The following guiding questions were formulated to aid in the investigation of the overarching research question:

(1) What different approaches did participating teachers develop to teach socioscientific issues in their classroom settings?

(2) What were the perceived challenges participating teachers faced while teaching socioscientific issue-based lessons?

(3) What strategies did the participating teachers develop to tackle challenges faced in teaching socioscientific issues?

By borrowing phenomenographic perspectives, I detailed three qualitatively different ways the teachers approached SRSE in Chapter 4. The data was organized into categories representing how the teachers' understood, enacted, and worked through challenges related to SRSE, answering the research questions. The categories included (1) developing a balanced stance to new socioscientific issue-oriented curricular initiatives, (2) promoting individual transformations through SRSE, and (3) promoting students’ engagement with collective social actions. In Category 1 (Balanced), the teachers focused on preparing students to be engaged critics of socioscientific issues (SSI) by developing their cognitive and conceptual knowledge related to each Vision of scientific literacy. In Category 2 (Transformative), the teachers focused on promoting students' ability to forward personal actions on SSI by developing their attitudes and beliefs. In Category 3 (Collective Action), the teachers focused on promoting students' engagement with collective social actions by developing student agency.

Within the categories, the teachers developed strategies to overcome challenges. In Category 1 (Balanced), the teachers' viewed challenges as being within their loci of control, prompting them to orient their engagement with SSI as one that builds on prior knowledge and experience. To overcome their perceived lack of content knowledge, they adopted a mindset of curiosity, approaching unknown areas with a willingness to expand their understanding. To address their discomfort in discussing personal values related to SSI, the teachers acknowledged that values are inherent in all actions and communication. They felt they needed to be discussed lest students adopt the values of others without scrutiny.

In Category 2 (Transformative), the teachers perceived SRSE challenges as influenced by factors within and outside their control. One identified was supporting students' belief development despite their students and their inexperience in engaging in such practices. The teachers employed targeted activities to build students' skills and adopted some practices of their peers to address this challenge. The teachers also acknowledged challenges in aligning their SRSE goals with the broader school context. The teachers employed a supported and negotiated implementation strategy in response. This involved respecting the perspectives of parents, students, and colleagues while working on expanding their school’s science possibilities.

In Category 3 (Collective Action), the teachers perceived the challenges as a complex interaction of internal and external factors. For example, their positions and perspectives towards SSI in tandem with those of their colleagues, students, and school context. All influenced the selection of SSI topics for their classroom. To promote students' engagement in collective social actions, the teachers felt a need to take a leadership role in overcoming these challenges. They faced the challenge of supporting students in collective action related to SSIs. To address this, the teachers sought pedagogical approaches to promote action-taking and carefully considered their role in promoting student action. They sought to balance providing opportunities for action and allowing students autonomy in their choices.

The constructed categories – balanced, transformative, collective action – elucidate aspects of teacher learning in an SRSE context. As consistent with phenomenographic perspectives, learning is defined as a change between qualitatively different ways of experiencing SRSE. The learner gains the capacity to experience SRSE in more complex ways than before. Chapters 4 and 5 highlight how the teachers learnt about SRSE in terms of a more complex discernment of students' level of participation, the object of student transformation and orientations to SSI engagement (Table 14). This view of learning implies that the teachers became more capable of discerning aspects of SRSE teaching and learning than before; they were simultaneously focally aware of more aspects that influenced their SRSE practices.

In this study, the strategies the teachers' employed to overcome their perceived challenges allude to how they became more focally aware of SSI-based pedagogical practices. This shows how dwelling within one approach served as a base to develop pedagogical insights and personal reflections to explore other approaches. These insights and reflections represent 'deliberative steps' that delineate means towards SRSE construed more broadly, in its varied potential forms, rather than terminal ends. They provide specific examples exploring the nuances of how the teachers in this study addressed challenges in teaching SRSE. Learning and classroom experience the teachers engaged in through the Learning study advanced three teacher attributes I deemed essential for SRSE development. They represent recommendations to further support SRSE practices, serving as guideposts for teachers and teacher educators. Finally, distinct design features and learning experiences the teachers deemed essential for SRSE were discussed in Section 5.3. Some included teachers' preference for incorporating SSIs to frame instruction and using stakeholder analysis to explore those issues' social, ethical, and justice-oriented aspects. In the next section, the limitations and delimitations of this work will be discussed, followed by a discussion of the study's significance and implications.

6.2 Limitations and Delimitations

A limitation of this study arises from the context of the school. Several independent and public schools were contacted for recruitment (see Section 3.2). However, the decision was made to work with only one institution, given evolving public health from the COVID-19 pandemic. Cranberry High is an independent school which takes tuition payments from students. It has resources from tuition that many other schools may lack. These resources can manifest in numerous ways, like costs incurred on students for field trips, the breadth of school clubs offered, scholastic equipment, etc. In this light, the probing of how SRSE was employed and enacted in this study was limited to teachers in an independent school. It could not be extended to schools of different resource levels or structures. Different types and amounts of resources may impact the challenges faced when exploring SRSE and how they might be addressed.

Another limitation of the school context was the traditional science teaching and learning culture in which this study was conducted. This culture substantially influenced the challenges the teachers reported in this study and, therefore, their understanding and enactments of SRSE. School science departments interested in social responsibility, pro-environmentalism, socio-ecojustice, or pedagogies which move away from traditional science education practices would be of interest to further explore diverse understandings, enactments, and challenges of SRSE. The additional insights and reflections contributing to the adoption and critique of SRSE could thus be defined and expanded based on further contextual exploration.

The limitations of the COVID-19 pandemic deserve some attention. Though the word 'unprecedented' is now a cliche to describe the most intense of the pandemic period, it nonetheless sums up the educational context of March 2020 to June 2021. Any educator working in schools during this time needs no reminders of the personal, emotional, and pedagogical hardships endured (e.g., Kush et al., 2022). This study recruited participants, conducted interviews, held group meetings, observed classes, and disseminated teacher knowledge from April 2020 to June 2021. Meetings, interviews, and observations were held outdoors, socially distanced, in inclement weather, through masks, through plexiglass, between school closures, between regional lockdowns, and online with little warning or time to prepare. Two things are worth mentioning here. First, the courage and conviction of the participating teachers and their students. This may be inappropriate in the body of a dissertation, mainly as history dulls memories of 2020 and 2021. Still, Mike, Dave, Nicole, Faye, and their students continued in this project, given everything else going on, and that should be recognized.

Second, how the findings of this study might differ in a non-pandemic context is difficult to ascertain. For example, in-person meetings might have led to new conversations and reflections propelled by the affordances of, for example, authentic relationships and communication in-person professional development can offer in comparison to online modalities (e.g., Stokes et al., 2020). However, this study's online meetings around post-lesson conferences used video recordings. This was because in-person observations for non-school-based personnel (i.e., individuals not directly employed by the school) were not allowed. This provided opportunities to rewatch classes and uncover nuances which may have been missed in in-person or online observations (e.g., Suh et al., 2021). In this context, trade-offs between pandemic-induced changes are numerous and deserve future research. What can be said is that throughout the study, the perseverance of the "holistic situation" (Guba, 1981, p. 84) brought focus. This is consistent with conducting research in a naturalistic paradigm.

In preserving the holistic situation, a limitation of this study concerns the limited focus brought to the transition from an in-person Learning study to a mixed in-person and online model. In the body of this dissertation, I did not discuss the impacts of the online environment on teacher learning or my research. Following phenomenographic perspectives, these areas did not appear to be of interest to the participating teachers and their experiences in the Learning study. In one sense, the teachers had been teaching online since March 2020, and when the Learning study was forced online in November 2020, many of the 'kinks' and 'novelty' of this transition had worn off. This may have made the modification unworthy of attention for the teachers, as videoconferencing was a fact of life when dealing with rolling COVID-19 restrictions.

Moreover, the transition to mixed in-person and online models was dynamic. This likewise could have made any online/in-person changes unworthy of mention by the teachers. For example, group and ISMs (individual support meetings) for lesson planning and reflection were held in person until November 2020, when they moved online through video conferencing software. Following, the teachers of the research lessons taught the research lessons in person, and school-based personnel (i.e., members of the Learning study employed by the school) available also observed them in person. Lesson observations for non-school-based personnel – or personnel not employed by the school and therefore barred from entering due to their activities being deemed 'non-essential' – were conducted online through the same video conferencing software. Lessons were audio-video recorded as a by-product of the video conferencing software, allowing them to be watched later. Finally, ISMs were held online and in person, given whichever COVID-19 restrictions were in place. This mishmash of online and in-person modalities blurred the lines between each component's significance to the Learning study process and products. As a case and point, online and in-person meetings between any combination of Learning study members were often held in the same week depending on restrictions in place and if socially distanced gatherings were feasible.

In my view, while a discussion of the effects of the online environment on the teachers' learning and my research is not negligible, one of the prime impacts on the effectiveness of online professional development has to do with the level of social, emotional, and instructional support provided to participants (Stokes et al., 2020). In online environments, these supports are often lacking (Stokes et al., 2020). The current study was both online and in-person, and, for the teachers involved, in-person for lesson observation since the school never closed; instead, non-school-based personnel could not attend. As such, the relationships among participants (facilitator included) necessary for social, emotional, and instructional support might have been developed before the online transition, maintained through individual meetings, and buttressed by the teachers' continued contact in schools. Framed this way, the organization of the current Learning study has the potential to overcome a critical challenge faced in online professional development formats (Stokes et al., 2020) and is worthy of further attention.

A limitation of the study could be the small sample size of teachers participating. Many school-based COVID-19 restrictions barred non-school-employed personnel from entering schools. As a result, this research's original participant recruitment numbers had to be scaled back as new restrictions were implemented. Despite the limited statistical generalizability of the results (Tan & Nashon, 2013), the categories of description depicting the teachers' experiences enacting SRSE can still illuminate and inspire different, and potentially more powerful, ways of perceiving SRSE in other contexts (i.e., analytic generalizability [Schwandt, 2014]). These different ways might work to expand science teaching and learning cultures of schools, engage students in focused criticism of some of the harm produced by SSIs, prepare students to formulate action plans for future implementation, develop students' attitudes towards complex and value-laden topics, and support students in acting in ways which seek to contribute care for themselves, others, and the environment. These more general-level conclusions align with phenomenography and qualitative and interpretive studies (Lincoln & Guba, 2013; Taylor & Booth, 2015), which aim to offer transferable principles to inform practitioners' practice situations and serve as a basis for future research to refine the suggested conclusions.

A delimitation of this work is the lack of student data presented. Analyzes of post-lesson surveys, artifacts of students' work, and student conversations were conducted by the teachers and shared in group and individual meetings. Owing to the focus of the research questions, these areas were not presented. In addition, with no 'control' groups among students (as is common in some Learning studies [e.g., Pang, 2010]), claims that SRSE or 3-VSL had casual impacts on student learning over other 'regular' approaches cannot be made. This necessarily muddies the criteria by which one could conclude that SRSE or 3-VSL was 'effective' in stimulating certain student learning outcomes, such as changes in student's conceptual understanding, beliefs, or agency. What is presented in this dissertation are teachers' perceptions of improved student outcomes. While these perceptions have their own value in expanding science teaching and learning scholarship (e.g., Vikström, 2014), future research could investigate student learning based on 3-VSL or SRSE to refine both in practice situations.

6.3 Significance, Implications, and Future Research

This section highlights the significance, implications, and future research directions for SRSE practice; teacher education; teacher professional development; theory; future Learning studies; and curriculum and policy.

6.3.1 Implications for Practice: Exemplars for SRSE

An area of interest in this dissertation is practical examples teachers could build from for SRSE work. The teachers in this study felt that their lessons were valuable in promoting their students' engagement with SSI. They can serve as resources for other educators (Appendix E, F, G). For example, the lessons on climate change education provided by Mike could serve as a fruitful base for further iteration if a goal is to have students develop action plans for mitigating and adapting to climate change. Likewise, Nicole's lessons on COVID-19 control measures highlighted how SSIs' differential social and environmental impacts could be weaved into classroom spaces. How Nicole fostered her students' understanding of diverse perspectives of the same SSI could be extended to other issues or topics (e.g., climate change reparations, environmental racism, etc.).

Aside from specific lessons, similarities and differences in design features could also be adopted. SRSE lessons in this study were always designed around an issue and were presented to students using some form of stakeholder analysis (e.g., Nicole's use of future webs). The teachers also explored the issue with students through carefully scaffolded steps so the students could incrementally gain familiarity with the complexity of the problem and the skills needed in its exploration. The teachers' ensured that learning experiences included using scientific ideas and theories and that students were engaged in higher-order practices (e.g., argumentation and position-taking). These learning experiences could be further enhanced through inquiry-based projects and incorporating Nature of Science themes (as discussed in Chapter 5).

6.3.1.1 Supporting Collective Action with SRSE. Another area of interest for teacher practice is for those interested in engaging students in collective social action. The teachers used action invitations in this study to enact critical literacy components. However, several questions remain. For example, if invitations are provided, and no student takes them, what then? How might invitations be made more enticing and meaningful?

First, as explored in this study, the choice of SSI matters. Teachers, students, and school-wide perceptions of the issue will affect how it can be investigated and acted upon. Though the topics chosen by the teachers in this study were diverse, including racist naming practices of diseases, 'bird strikes,' cancel culture in scientific discovery, climate change, and pandemic restrictions, further issues and the contextual factors pertinent to their inclusion or exclusion could be explored. One line of questioning from Chapter 5 includes the degree to which an SSI is *viewed* as political or apolitical in a school setting, the mechanisms by which this categorization changes, and the degrees of action condoned to address the issue based on the categorization. This exploration might allude to which design features and learning experiences might be particularly advantageous to specific issues and what types of SRSE approaches might be most appropriate given particular contexts. For example, systemic racism manifested in scientific research, when compared to climate change-related issues, likely requires different approaches, lesson design features, and learning experiences to engage students best.

In addition to research exploring the types of SSIs pursued, this work points to further exploration of strategies that support students in enacting their SSI-based decisions. Recently, Herman (2018) and Herman et al.'s (2019) work demonstrated a positive relationship between students' Nature of Science understandings and their willingness to act to resolve an SSI. Continued research in these relationships could be pursued (e.g., Zeidler et al., 2019).

Similarly, approaches using social justice science issues (e.g., Morales-Doyle, 2017) and empathizing science teaching (e.g., Zeyer & Dillion, 2019) could be pursued for their potential to motivate students to act. Given their explicit political nature, social justice science issues differ from SSIs. When used in a critical literacy context, their exploration seeks to "understand and eradicate social domination and inequality by addressing it in local contexts" (Morales-Doyle, 2017, p. 1036). As a result, the connections between SRSE, social justice science issues, and their potential in developing students' commitments to their local communities is a line of inquiry that pushes more deeply into the collective actions the teachers in this study envisioned. This work supports the exploration of social justice science issues in SRSE contexts.

According to a study by Lee et al. (2013), fostering empathy is fundamental to honing moral reasoning abilities. These abilities, in turn, can inspire individuals to take meaningful action. Hodson (2014) terms this 'learning to care' before one can 'learn to act.' Lee et al.'s (2013) research, among others (e.g., Herman et al., 2018), suggests that the continued fostering of empathy and compassion can help to address the disconnect between intentions and actions among students, as highlighted in this study. Zeyer and Dillion's (2019) description of reflective equilibrium could be employed with students to aid in building empathy. Dovetailing from this recommendation, additional materials or time exploring, hearing from, and understanding the impacts SSIs have on others could also be pursued. These practices may be valuable ways to facilitate empathy and more sustained action (e.g., Morales-Doyle, 2017).

Chiefly, these examples and ideas for continued SRSE practice attempt to honour teachers' knowledge of their context. The different approaches, design features, and learning experiences are recommendations to help educators select the SRSE approaches most appropriate for them (e.g., Hodson, 2003). As demonstrated in the findings, there is value in each SRSE approach described, design features included, and learning experiences implemented. What we might draw from the participating teachers in this study is their willingness to begin SRSE approaches in whatever form is deemed most appropriate.

6.3.2 Implications for Teacher Education and Teacher Professional Development

A significant finding from this study deals with the essential teacher attributes and permutations pertinent to SRSE practice. Like the lesson design features and learning experiences, the attributes can focus teacher educators in program planning and offer teachers guideposts in self-directed learning. For example, becoming familiar with specific SSI concepts, context, and action pathways provides an appropriate starting point for several SRSE approaches. With this familiarity, exploring pedagogies for issue engagement could also be pursued, followed by ways to judge students' skills to engage with those pedagogies.

Desirable teacher attributes that position teachers as learners can be developed via teacher-teacher group work in which collaboration is a priority. In such spaces, honesty about knowledge and pedagogical limitations, positioning oneself as a knowledge facilitator and contributor, and a willingness to negotiate with different perspectives colleagues and students might have can be fostered. Teacher education and professional development approaches like Learning study are one avenue of such collaboration (e.g., Miechie et al., 2019; Royea & Nicol, 2019; Tan, 2018). Generally, and as illustrated in the findings, sharing beliefs toward SRSE (and science education in general) should be encouraged as a catalyst to practice a learners' mentality. The explicit articulation, examination, and critique of such beliefs may reveal limitations in the teachers' current pedagogies, motivate them to align their practices with their teaching goals, and try out novel approaches. As shown, all of these can be promoted via a Learning study context.

Notably, the essential attributes of being aware of the school's position on specific issues and pedagogies for engagement will have to happen in practice situations. School contexts have long been identified as influencing new science education practices (Aikenhead, 2006), and supporting teachers in uncovering the constraints and affordances of their context is an important area of continuing scholarship (e.g., Bencze et al., 2006; Can et al., 2017). On a teacher education side, this is where school advisors for new teachers become essential to facilitate those discussions and ideas. For teachers within school systems, focused reflection on their school context's explicit and hidden priorities requires attention (e.g., Eisner, 1985; Wong, 1995). This may hone teachers' ability to differentiate SSI, including their nature and the kinds of action desirable and prudent given a specific context. Should schools' priorities run counter to a teacher's desired outcomes, the results of this study indicate that collegial support, in terms of colleagues or admin, is vital. They provided the building blocks for a negotiated uptake of novel and potentially controversial issues and pedagogies.

In unsupportive systems or systems in which restrictions prevent certain issues from being taught, teachers might find it difficult or infeasible to continue pursuing SRSE (e.g., given the fear of retaliation or job security). The results of this study do not advocate pursuing issues or pedagogies that endanger educators' livelihoods. Beginning SRSE in a way most appropriate for the context is encouraged. As Nicole pointed out, even a ten-minute conversation, prudently chosen and cautiously managed, can lead to new ideas and student learning. As found in this study, after each SRSE engagement and subsequent reflection, new ideas and pathways to more diverse outcomes and means to achieve them can be ascertained.

6.3.2.1 Implications for Understanding and Articulating Teacher Learning. A significant finding pertains to insights into the nature of teacher learning in SRSE. Consistent with Learning study literature, teacher learning is a significant outcome of teachers participating in the professional development approach (Bruce et al., 2016; Hervas, 2021; Ko, 2019a; Nilsson & Vikström, 2015; Pang & Marton, 2003). In this study, the phenomenographic framing (Marton & Booth, 1997) helped to elucidate how the participating teachers learned in terms of their increased discernment of critical aspects to improve students' learning of SSI. Consequently, the teachers were able to develop more complex ways of approaching SRSE than were previously possible. Collectively, the findings allude to the kinds of teacher learning that has taken place (e.g., that justifying personal positions on SSI is important to aid students in their own justification), as well as the deliberative steps and conditions that supported the teachers' learning (e.g., enacting and reflecting on pedagogical aspects of a controversial reading to highlight the importance of justifying personal positions on SSI and the importance of collaboration to articulate and reformulate personal beliefs related to the justification of personal positions). Following Clarke and Hollinsworth (2002), these insights are important for future teacher education and professional development because "if we are to facilitate the professional development of teachers, we must understand the process by which teachers grow professionally and the conditions that support and promote that growth" (p. 947) (e.g., the school context which is touched upon in Sections 5.2.1.4, 5.2.2.3, and 6.3.2).

Starting with the kinds of teacher learning that have taken place (e.g., Table 14), teacher educators and professional development leaders can use these results to design instruction and programming. For example, focusing on the development of students' conceptual understanding, beliefs, or agency could be used to organize or analyze science education learning experiences in initial and in-service teacher education settings. Likewise, students' level of participation could draw similar attention as teacher-learners are guided to explore the possibilities and limitations of focusing students' participation on critical engagement, personal actions, or collective actions.

The findings also provide specific examples of the deliberative steps and conditions that helped promote the teachers' learning to teach SSI, which could, by extension, be adapted to other contexts. Specifically, the deliberative steps provide tangible evidence of how the teachers addressed challenges in teaching SRSE, which differed according to their adopted approaches. The conditions provide evidence of the Learning study elements that supported the deliberative steps to promote learning.

For example, extant literature highlights the importance of dissecting, articulating, and justifying personal positions on issues in effective Vision III-oriented SSI-based instruction (Dos Santos, 2009; Hodson, 2011, 2020; Lee & Witz, 2009; Morales-Doyle, 2017). The deliberative steps by which the teachers in this study achieved this position can be thought of as a four-step process. (1) The teachers' engagement with the Hodson (2014) reading (primarily, the part that teachers *must* share their position and values on SSI with their students) initially prompted them to reflect on sharing personal positions and whether values should be included in classroom discourse. As (2) some of the teachers taught their research lessons, they leaned into those values, as, for example, Dave discussed his ideas on cancel culture in scientific discovery. These lessons (3) prompted the teachers to reflect if values should, and even could, be genuinely 'hidden' from students. These reflections, in turn, (4) prompted the teachers to pursue new enactments where they shared their values, as an example, through Mike's justification to his students of his attendance at a climate march.

In this example, the deliberative process can be described as flowing from (1) the teachers' initial beliefs of ‘no values talk' interacting with a Learning study reading (Hodson, 2014), to (2) the teachers’ enacting that reading in a practice situation, to (3) the teachers’ reflecting on that practice regarding their initial beliefs and thus transforming it, to (4) the teachers’ enacting the transformed belief back to practice. This deliberative process is important for Vision III-oriented SSI-based research as it highlights the ‘steps’ the teachers in this study took to begin to share their values on select issues with students. These steps could serve as inspiration for future research and practice. For example, pointing to the potential of a stimulating or ‘controversial’ reading to kick-start a reflective process.

The four-step deliberative process beginning with the ‘no values talk’ engaged by the teachers was supported by the conditions of the Learning study. Experimentation (i.e., the teachers’ engagement with classroom research) and collaboration allowed the teachers to reflect on their own and others' enactments of values in a classroom and discuss the possibilities and limitations. As a case in point, the teachers debated on ‘no values talk’, carefully weighing the advantages, disadvantages, and ethical considerations of sharing their values and positions on a particular SSI with their students. This form of collective reasoning, reflection, and experimentation could be adapted by other teacher educators, serving as inspiration for future research and practice. Therefore, the deliberative process and conditions in tandem are one tack professional development leaders and teacher educators can draw from. They can be used to design SRSE learning experiences to explore the role of value sharing in SSI-based teaching and help teacher educators identify and respond to similar instances of teacher learning occurrences.

Another example pertains to the teachers' desire to develop students’ attitudes and beliefs to prepare students for personal actions. This deliberative process can be characterized as containing four initial steps and three subsequent steps. Upon (1) the teachers’ engaging students in stakeholder analysis (e.g., Nicole's use of future webs), the teachers (2) reflected on their classes regarding their original goals. The teachers felt that although student attitudes may have been developed (e.g., Nicole's view of students' increased levels of compassion for those affected by pandemic restrictions), their student's personal actions were lacking; for example, Nicole's students still flaunted school-based COVID-19 rules. From this outcome, the teachers' (3) reflected that certain students' learning skills deserved more focus, like in Dave's classes, his students' discussion skills. This led the teachers to (4) seek ways to further develop select student skills in future enactments. For example, Dave used a pre-research lesson to support his students’ discussion skills before moving forward with the rest of the research lessons. However, the teachers’ initial reflection on student skills also prompted them to reflect on (5) the school context and, specifically, the science education culture. Through this reflection, the teachers realized that (6) the school's traditional science teaching and learning culture also impacted their students' skills. As such, they were prompted to (7) address the constraints brought on by the school context by finding affordances those constraints permitted, for example, Dave aiming to implement SRSE in non-Advanced Placement (AP) classes.

In this example, the seven deliberative steps highlight processes and conditions critical to SRSE seeking to support students' personal actions. Condition-wise, the contextual collaboration and diverse membership of the Learning study allowed the teachers to reflect on their and others' enactments of developing students' attitudes in a classroom, discuss the possibilities and limitations, the reasons for those limitations across grades, the identification of scaffolding student skills to address limitations, and the identification of the school context as a constraint needing attention. Like above, these deliberative processes and conditions offer insights for future teacher professional development and teacher education (e.g., the beneficial practice of attending to scaffolding strategies to help ease students and teachers into learning about SSI). However, what I also find interesting is the connections between deliberative processes.

For example, the deliberative steps mentioned above can be considered part of more extensive teacher-learning processes. When engaging students in discussions about attitudes and beliefs toward select SSIs (the seven-part process), the teachers in this study shared their views with pupils and often made explicit how they arrived at those views (the result of the four-step process). As such, the initial deliberative steps leading to the teachers bringing up values trailed directly into supporting students' attitudinal development. Akin to some form of nested relationship, the two sequences of deliberative steps can be seen as extensions of one another.

6.3.2.1.1 Toward a Cascading Deliberative Process Theory of Professional Learning. As tied together, the deliberative processes described above can be considered steppingstones that mediate new connections teachers might make between their understandings and teaching of SRSE. These connections concomitantly aid teachers in developing their capacities to engage in classroom research, develop practice, and devise novel instructional approaches that effectively promote the learning of SSI; all of which can be supported via the Learning study. Thus, further research exploring connections between these deliberative processes and how they ‘cascade’ into new deliberative processes could be of interest to researchers to develop a greater understanding of prolonged formulations of teacher professional learning.

The study of these nested deliberative processes, their connections, and the conditions which support them can be supported by what I have termed a ‘cascading deliberative process’ theory of professional learning. This theory arises from my analysis and requires more work to develop outside the scope of this dissertation (e.g., being used in conjunction with Clarke and Hollingsworth's Interconnected Model). The cascading deliberative process theory takes a specific view of the connections between deliberative processes, how a single ‘phase’ can be defined (e.g., the four and seven-step processes detailed above), and what supports their cascading connections. Questions I find interesting for further exploration include: What starts a deliberative process cascade? What breaks it down? What conditions best support it? What determines how many deliberative processes occur per phase (e.g., to what degree does school context and teacher prior knowledge influence a four or seven-step phase)? What mediating processes connect each phase of the cascade? What domains of teachers’ world (e.g., beliefs and attitudes, practice, student outcomes) connect each phase? What level of study (individual or group) is best suited?

Cascading deliberative processes are multi-faceted and non-linear. They are, therefore, well situated within a Learning study – or broader teacher inquiry or action research –context where the cyclical phases are likewise non-linear. Their progression is contingent on the emergent discourse (Tan, 2018). This theory can, therefore, add to the growing interest among teacher education scholars in documenting outcomes from professional development that moves past "discrete changes in knowledge and beliefs, practices, and student outcomes" (Yurofsky et al., 2019, p. 11) but capture the messy and unfolding learning of educators in practice situations. This also contributes to a more nuanced understanding of Learning study 'learning,’ including the complexity and possible influence of the educational setting (Trigwell, 1994) or ‘change environment’ (Clarke & Hollingsworth, 2002).

The potential of documenting and analysing connected and cascading deliberative processes are not restricted to SRSE. Future research could consider this mapping and structure of successive teacher learning as an analytic tool. For example, Clarke and Hollingsworth's (2002) Interconnected Model could be explored when viewed as part of 'cascading' growth networks. This might showcase domains of teacher learning, empirical evidence of their change, and identification of structural patterns over more extended periods that, when analyzed, might allude to conditions for learning or structural patterns between domains requiring additional research and attention. This line of inquiry could contribute to the extensive research literature aiming to explore the longevity of in-service teacher education programs (e.g., Desimone & Stuckey, 2014; Hargreaves & Goodson, 2006).

6.3.3 Implications for the Use of the Three Visions of Scientific Literacy

Theoretical perspectives "systematically structure a teacher's understanding of his or her work in a particular context" (Stenhouse, 1975, p. 157) which aids in planning, implementing, and reviewing practice. In teacher professional development, theoretical perspectives provide teachers lenses to view student learning, make pedagogical choices, and understand teaching practices (Elliott, 2012; Runesson, 2016; Tan, 2014a). Theoretical perspectives direct teachers' attention to different things, including how and what they focus on in their practice (Lo, 2016). The explicit employment of a few theoretical perspectives has been reported in teacher professional development approaches, such as Learning studies (e.g., Martin & Towers, 2016; Tan et al., 2019b). As such, the employment of theoretical perspectives from the 3-VSL is significant for its potential to (1) influence future science education professional development and (2) specifically extend Learning study scholarship. The first point is picked up in this section. In section 6.3.4., 3-VSL's relation to Learning study trends will be addressed.

The 3-VSL was initially chosen to frame the SRSE Learning study because it emphasized the mutually supportive connections between different goals of science education and contained components of science education with which most science teachers would be likely familiar (the conceptual literacy Vision or Vision I). The theoretical perspectives distilled attempted to keep the generic and connected character of the 3-VSL, aiming to facilitate a diverse exploration of SRSE. In this study, the 3-VSL was drawn on by the teachers to pursue SRSE approaches most suitable to their context, interest, and students. It was also drawn to pursue SRSE approaches unfamiliar to their context, interests, and students. The use of the 3-VSL to both enrich existing practice and foster exploration of new practices is a strength of the theory as employed in the Learning study. Practitioners focused on SRSE or SRSE-related approaches (e.g., propelling pedagogical ideas prioritizing the interrogation of SSIs) could explore the 3-VSL further.

One line of questioning relates to the employment of the 3-VSL in supporting teachers' exploration of literacy-focused learning outcomes (Pang, 2010, 2019; To & Pang, 2019). Recall Nicole's focus on students' ability to use scientific evidence to propose and evaluate actions to reduce harm from pandemics and pandemic restrictions. This learning outcome has generative learning potential – a potential used to describe literacy-focused learning outcomes (Pang, 2019) – namely, evaluating and proposing actions to reduce harm can be applied to other contexts (Holmqvist et al., 2007; Marton, 2006). Mike and Dave's intended learning outcomes demonstrate similar potential. The teachers drew on the 3-VSL to explore these generic capabilities as multiple concepts and their integration and synthesis could be captured in the connections between or inside individual Visions of scientific literacy. Learning outcomes of this type are appropriate to SRSE or SRSE-related approaches, as interrogating SSIs requires integrating and synthesizing multiple concepts. The 3-VSL provides ways to explore such aims.

Another line of questioning relates to the usefulness of the 3-VSL as a reflective heuristic. In the context of science education research, how teachers in this study pursued and utilized the 3-VSL in practice is significant. It gave clues to elements of the "invisible hand"

(Bencze, 2017, p. 23) which might stymie non-traditional and more activist-oriented science education ideals. As shown in this study, the 3-VSL provided a starting point for developing cascading deliberative processes. This is partly due to the reflective possibilities engendered to the 3-VSL by the professional development approach (i.e., Learning study). In the approach, several goals for science education – their justification, assumptions, and specific aims – were put forward. The teachers were then prompted to use the theory to articulate and justify their own aims and reflect on those in relation to their context and the Visions. In this way, the 3-VSL acted as a mirror for various goals for science education, where deep-set values at the level of the individual and the local school context could be uncovered and understood. This, in turn, provided opportunities to name elements of the 'invisible hand' (e.g., in this study, the teachers' beliefs in ‘no values talk,’ constraints brought by collegial opposition, constraints brought by traditional school culture and related students' skill sets, and teachers' beliefs around action impositions) and, through the professional development discourse, provide ways to address them.

Practically, this offers recommendations for other science education researchers seeking to propel activist science education. The 3-VSL can be drawn on as a reflective heuristic to uncover elements of the 'invisible hand' and, through professional development, ways to address them. However, in uncovering these elements, this process cautions future science education research from moving too quickly to promoting activist science teaching without careful deliberations on the starting points of teachers, their context, and their students.

When exploring school topics for activism, this study's results suggest that slow, methodical, and cyclical support is required to aid teachers in clarifying and expanding their views of what science education is and means as they explore and address elements deemed important for their own goals. This can be seen as a power of the 3-VSL in tandem with the professional development approach employed in this study, Learning study. More activist orientations to science education are suggested, justified, and open to exploration. However, their pursuit is not mandated. This upholds the tenants of teacher professional development using action research and its participatory ethos. The professional development is designed to engage in inquiry *with and for* teachers, respecting their capabilities as knowledge producers, scholars, and agents that can drive change in their school systems and classrooms.

However, the recommendation of slow and cyclical, while potentially effective in exploring and addressing barriers to activist-oriented science education, does little to address SSI-based harms *now* that desperately need attention. This is akin to Hodson's arguments (1999, 2003, 2010, 2011, 2020) that what is needed is engagement in action rather than talking about action. In this light, while the 3-VSL appears to be a suitable tool to begin growth to new science education ideas, if a goal is to explore politicized science education at the outset, the issue chosen in tandem with 3-VSL exploration might provide a more direct path.

For example, climate change as an issue deserving action, mobilization, and activism is increasingly recognized and promoted across policy, practice, and research. As found in this study, this area is relatively easier to be an activist for, for myriad reasons (many of which were covered in Section 5.3.1.4). However, along similar inquiry lines as cascading deliberative processes, future research exploring the connections between topics and their potential to further interest or participation in activism would be of interest.

I propose the idea of a 'catalyzing issue' to kick-start deliberative processes along an expanding network of pro-SRSE actants (i.e., what Bencze [2020], drawing from Actor-Network-Theory [Latour, 2005] and Foucault [2008] might call a ‘dispositif’) as one area of future inquiry. For example, might drawing activist aims for climate change uncover the incredible socio-economic, colonial, and racial issues that often remain hidden behind the rhetoric of 'staying within the limits of X degree of global temperature warming' (e.g., Salas, 2021; Waldron, 2021)? Might this new understanding gestate further activist initiatives for more diverse topics? The nature of 'catalyzing issues,' how they are viewed by the context in which they are explored, their justification through scientific evidence or other knowledge systems, their placement in curricular documents, and the utility of 3-VSL for teachers and researchers to explore each component are more direct lines of questioning.

6.3.4 Implications for Implementing Future Learning Studies

A significant finding from this study relates to the rendering of another Learning study case. Broadly, how the Learning study encouraged teachers to locate their classroom teaching in broader school and educational contexts, focus on the theoretical perspectives they engaged with, and collaborate in designing and evaluating lessons constituted important Learning study experiences that supported the teacher learning observed in this study. How these facets of the teachers' Learning study experience promoted their learning has been well documented in other Learning study cases (e.g., Attorps & Kellner, 2017; Hervas, 2021; Vikström, 2014). The discussion in this section thus iterates the importance of these experiences afforded by the Learning study while contributing another case (e.g., framed using 3-VSL, exploring SRSE, and in Western Canada) of Learning study to build knowledge about teacher development in the field (Ko, 2019a; Lo et al., 2006; Lo et al., 2007). Ko (2019a) and Lo (2009) have underscored the importance of developing individual cases of Learning study to develop a more robust understanding of how the approach can be applied in different educational contexts.

The focus on school context allowed the teachers to learn how certain issues and pedagogies within SRSE could be best pursued and explored given the constraints and affordances of their local school context. The teachers became attuned to 'what science is and means' to their student body and colleagues and developed insights into ways SRSE could be most efficaciously employed. This included reflections on which courses and for what topics SRSE might be best pursued. It also included reflections about how their school's teaching and learning culture influenced their students' collective skill sets and ways to bring greater attention to skills pertinent to SRSE practices.

Framing the Learning study using the 3-VSL gave the teachers a fertile base for SRSE exploration and reflection. The 3-VSL became a lived theory (Vikström, 2014), taking on canonical use in the teachers' practice. The teachers drew on the 3-VSL to seek out knowledge domains and pedagogies they felt were necessary for their varied SRSE approaches. Similarly, the 3-VSL became a sense-making and articulation tool, drawn on by the teachers to highlight new ideas and goals for science education and uncover ways to achieve them.

The focus on collaborative planning and evaluation of research lessons impacted the teachers' ideals and values for science education. As demonstrated in this study, the need to collaboratively examine and espouse beliefs around SRSE and SSIs appeared to serve as a precursor for teachers’ perspectives to be challenged or shifted in ways that are consistent with SRSE instruction. The articulation of beliefs is a consistent throughline to promote novel teaching practices in teacher professional development literature (e.g., Fuchs & Tan, 2022; Lewis & Tsuchida, 1998). Due to the unfamiliarity of teaching SSI, teachers should also be able to observe each other’s lessons and build on them in tandem with teaching their own. In this way, Learning studies' successive and iterative nature (e.g., Pang & Marton, 2003) is even more pronounced when teachers explore unfamiliar content and approaches.

Given the importance of the facets of the teachers' Learning study experiences above, the importance of these affordances in the current study that has (1) deviated from the employment of the dominant theory, variation theory; (2) dealt with a challenging aspect of teaching and learning science (i.e., SRSE); and (3) utilized a novel Learning study model (i.e., concurrent-and-successive), is worthy of further attention and will be discussed in the following subsection.

6.3.4.1 Future Learning Studies. The Learning study modifications made in this study are significant as they open pathways for continued research and respond to some contemporary trends in Learning study scholarship. This includes the diversity of theoretical perspectives employed, the complexity of objects of learning pursued, the expansion of Learning studies to diverse contexts, and the potential of online formats in supporting teacher learning.

As mentioned in section 6.3.3., the 3-VSL employed in this Learning study was a boon for teachers' practice and offered recommendations for future research and practice in science education. Therefore, this study provides an example of how different theoretical perspectives can be brought to bear in a Learning study. The insights and recommendations from Section 6.3.3 would have been different if different theoretical perspectives had been used. Based on the results of this work, theoretical perspectives in Learning studies do indeed draw teachers' and researchers' attention to different things and findings in different ways and for different ends (Lo, 2016; Runesson, 2016). It behooves researchers and practitioners of Learning study to continue exploring diverse theoretical perspectives that can best support teachers in their aims. This contributes to advancing the theoretical perspectives applied and the potential of the Learning study approach.

For the former, the teachers in this study began theorizing (e.g., Tan et al., 2019a) the 3-VSL regarding its pedagogical utility when conceptualized as a continuum or a Venn diagram.

For the teachers, the idea is that the confluence of all three Visions at once could be a teaching priority desirable over any Vision alone. This area could be tested further to see how an overlapping, instead of a linear model of the 3-VSL, might aid practice. Other areas of interest related to the depth of understanding of the 3-VSL and the resultant theoretical perspectives distilled. This could include other formulations of scientific literacy (e.g., DeBoer, 2000), tenants of each Vision on their own (e.g., Aikenhead, 2007; Roberts, 2007; Sjöström et al., 2017), or a focus on the space between Visions, drawing more explicit focus on their connections (e.g., as seen in Category 1 of this study where the teachers' focused on contextual-critical enactments).

Regarding the advancement of the Learning study approach, learning or pedagogical theories are most commonly employed (Elliott, 2012). This makes Tan et al.'s (2019b) neuroscience-framed Learning study seminal. The brain research theories they explored were neither learning nor pedagogical theories –notwithstanding the ability of teachers and Learning study facilitators to distill theoretical perspectives that can be applied to learning and teaching. Instead, the brain research theories provided teachers with ways to think about human cognition, which expanded possibilities to engage students in learning. This work draws inspiration from Tan et al. (2019b). The 3-VSL opens similar possibilities in Learning studies more generally.

For example, the 3-VSL aided the teachers in exploring literacy-focused objects of learning (Pang, 2010, 2019; To & Pang, 2019), as multiple concepts and their integration and synthesis could be captured in the connections between or inside individual Visions of scientific literacy. While important for science education (Section 6.3.3), using literacy-focused objects of learning is an important area of current Learning study scholarship. Learning study has come under critique for focusing on too narrow and simple objects of learning (Pang & Runesson, 2019), where minute and specific concepts or content are pursued (Dahlin, 2007).

Including more complex and ill-defined learning objects in Learning studies should continue. This is important at the senior school level, where objects of learning might be pitched across an entire unit, involving complex ideas appropriate for more mature students. Recall Mike's object of learning spanning his entire climate change unit or Dave's dealing with emergent research's social, ethical, and environmental impacts. More complex learning objects can support teachers in exploring what they deem most important and challenging to warrant the effort required to engage in a Learning study. Literacy-focused heuristics and frameworks (e.g., 3-VSL) as employed in Learning study provide one avenue to explore such objects of learning.

Importantly, if more complex objects of learning draw aim, appropriate theoretical perspectives to support them must be considered, among other factors (e.g., pre-/post-tests suitable to capture 'literacy'). There is a balancing act between theoretical perspectives explored and objects of learning pursued. Based on the results of this study, the depth and breadth of theoretical understanding are one consideration. Both should be pursued to the extent that it is of value to teachers' practice. For example, the 3-VSL described by Sjöström et al. (2017) builds from Bildung's socio-philosophical and educational tradition (Horlacher, 2016). That information was deemed neither prudent for the current Learning study nor the body of this dissertation. This points to the need for Learning study facilitators to be nimble with their employment of theoretical perspectives, especially when they are novel to the Learning study field and the objects of learning pursued. Reflexivity is required to best support teachers (Tan, 2014b).

In a Canadian context, modifications to Learning study are sometimes necessary given education system-specific norms and regulations (e.g., Tan et al., 2019a, 2019b). In this study, the concurrent-and-successive model was developed to accommodate the membership of teachers as well as their course schedules. Each teacher contributed to planning and evaluating objects of learning, lessons, and student data. However, every teacher did not teach every lesson. Instead, each teacher had their own research lessons they were responsible for. The Learning study model is concurrent in that individual research lessons under a broader theme were planned simultaneously. It is successive in that once one set of research lessons was complete and evaluated, another began.

These concurrent and successive Learning study cycles allowed the teachers to generate insights from one set of lesson observations and reflections and quickly implement them in another. This allowed for a culmination of 'best practices' based on how they effectively promoted student learning. This is akin to Elliott's (2012) description of propelling learning laboratories through Learning study. However, in this model, there was an intensity in learning opportunities as the Learning study cycles overlapped. All Learning study group members did not teach the individual teachers' research lessons. However, the teachers' discussions and reflections in collaboratively refining each other's lessons can be thought of as reinforcing the practice of praxis. For example, instructional strategies held together by theoretical perspectives (i.e., 'principles of procedure' [Elliott, 2012]) developed in one teacher's context were tested in another's for their pedagogically significant similarities and differences.

Typically, Learning studies comprise teachers of the same grade level working with the same object of learning (Ko, 2019a). However, the concurrent-and-successive model in this study allowed a more diverse membership of participating teachers. While 'original' Learning study models already contain diverse teacher groups (e.g., Attorps & Kellner, 2017; Tan et al., 2019a, 2019b), in a Canadian context, teachers teach a set number of courses per year or semester, which may or may not overlap with other teachers. As found in this study, this can make a Learning study targeting, say, Grade 9 Science challenging to undertake if only one educator is teaching Grade 9 Science or the other educators of that grade have competing commitments. In contexts where schools might not have enough teachers from the same grade level teaching the same subjects to form a Learning study, the concurrent-and-successive model provides an alternate approach others could adopt to include teachers of different grade levels and subjects. This extends examples of inter-grade Learning studies (e.g., Attorps, & Kellner, 2017; Tan et al., 2019b), which appear rare in Learning study literature, especially at a senior school level. The concurrent-and-successive model offers a pathway to include, and therefore study, Learning study groups of this nature. This model represents a theoretical contribution this study makes to the Learning study literature.

This study found that having diverse membership from across grades benefitted participants. The diversity of pedagogies, knowledge, and experience could co-mingle in the Learning study discourse. Of course, this is possible with teachers teaching the same grade as they will likely have different experiences teaching. However, in this study, the inter-grade knowledge gave a nuanced understanding of pupils' school-wide knowledge and experiences. This allowed for greater dexterity in planning research lessons to best support students.

Finally, the concurrent-and-successive model in this research provides supporting evidence of engaging in lesson observations and post-lesson discussions without teaching the research lesson (e.g., Widjaja et al., 2021). The teachers in this study could still decipher and apply insights from sets of lessons they did not teach to ones they did and uncover novel ways to improve student learning. This notion of watching before doing, as complemented by most of the concurrent-and-successive participants (cf. a teacher does have to go 'first,' thereby doing before watching), relates to the idiosyncratic and cyclical teacher change networks as described by Clarke and Hollingsworth (2002). At times, extensive refinement of ideas through successive reflections and enactments on practice, student outcomes, and personal knowledge are necessary for growth (Clarke & Hollingsworth, 2002). However, this research suggests that the extensive refinement of teacher ideas can occur through the observations of others. In this regard, a second-order perspective on teacher growth, as discerned and discussed by *participants* in a professional development scheme, would be of interest.

This notion is not novel in Learning study literature – or in other approaches in which teachers engage in collaborative inquiry as a form of professional development (e.g., quality teaching rounds [Bowe & Gore, 2016; Bowen, 2020; Gore et al., 2017], or school-specific 'ROUNDS' [Seidel, 2010]) – and is one reason lesson observations and reflection are so powerful. However, observation and reflection in lieu of teaching draw focus here. This process might encourage teachers to engage more with observations and reflective conversations as the 'teaching' component of research lessons is not their prime focus. In watching other group members' lessons, the teachers gather insights into student learning that might advance the lessons at hand or apply to their own eventual research lessons. This addresses the concern raised by some researchers that post-lesson conferences are merely verifications of lesson design choices (e.g., Sato, 2006; Saito, 2012) rather than focused deliberations on the influences of teaching choices on student learning. Theoretically, when using frameworks like Clarke and Hollingsworth's (2002) Interconnected Model (e.g., Grau et al., 2017; Justi & Van Driel, 2006), the inclusion of second-order perspectives on facets known to influence teacher growth (e.g., student outcomes or the 'domain of consequence') may provide additional pathways for teacher learning worthy of scrutiny and research. A contemporary application concerns watching videos of teachers' instruction (Widjaja et al., 2021). The concurrent-and-successive model can be used to explore questions regarding how second-order observations and conversations contribute to teacher professional development and learning.

Further exploration of the concurrent-and-successive model should be pursued, given the potential benefits to practice and research described. Further research is also needed to refine the model. In this study, exploring three different sets of research lessons with three different objects of learning supported by novel theoretical perspectives took time to discuss and explore. The time spent on these topics took time away from a deep exploration of the individual concepts each teacher felt were necessary to prepare for their lessons successfully. Moreover, the logistics and minutia of readying research lessons for enactment and evaluation (e.g., finalizing survey instruments, collating, and cleaning student data) could not be pursued, given the time frames of group meetings. As a result, the teachers felt they needed additional support from Individual Support Meetings or ISMs, as described in Chapter 3.

The necessity of ISMs is an important consideration for the concurrent-and-successive model in this study. A couple of items are worthy of mention. First, these meetings might be viewed as something the teachers could have done alone. In this study, this stance was evaded owing to the hardships of teaching during Canada's second, third, and fourth waves of COVID-19 infections. I felt that adding 'more' to teachers' already busy schedules in 2020 and 2021 was to be avoided, especially when extra support was explicitly sought. Second, these meetings might be seen as a way teacher-teacher collaboration is reduced. On the contrary, I argue that individual meetings might bolster the types of collaboration most sought in Learning studies, reinforcing the value of a facilitator or critical friend in Learning study models. This is because the teachers can come to group meetings subsequently prepared to discuss student learning and pedagogy rather than, for example, ordering survey questions. The ISMs supported the focus on student learning in Group Meetings because areas needing attention were already addressed.

Third, this extra support, if given, could be construed as a researcher trying to unduly 'influence' the progression of the Learning study. On the one hand, these meetings allude to the additional roles which might be necessary for Learning study facilitators, especially in challenging moments, such as a global pandemic. However, should these roles be sought by participants or deemed necessary by the facilitator, care must still be taken to bracket ideas and maintain the participatory ethos of the Learning study. Even so, bracketing does not negate the influence of the facilitator (i.e., in naturalistic inquires, trustworthiness strategies are never unassailable from critique [Guba, 1981]), and that is true for the ISMs. For this study, I followed Lincoln and Guba's (1985) trustworthiness guidance (Section 3.6) by opening my actions to the scrutiny of others through detailed accounts of each ISM (Appendix B).

Concerning these points, what should also be highlighted is that the complexity of objects of learning pursued and theoretical perspectives employed likely impacts the degree to which additional support is required. As more complex ideas are brought to a group, and theoretical perspectives are explored, the discourse of group meetings is affected. This may be especially salient if theoretical perspectives of a more generic nature (e.g., 3-VSL) are forwarded without explicit pedagogical implications (e.g., variation theory). For example, a discussion about SRSE, pandemic restrictions, climate change mitigation, cancel culture in scientific discovery, and the relations each have to critical literacy differs in character from discussing which critical aspects of atomic structure should be varied. One character is not better than the other; in the latter example, the depth of discussion might be expansive (e.g., Vikström, 2014). However, the added complexity and demands of praxis of the former require time for deliberation and support – time that might mean more meetings are needed.

This is an important consideration for practitioners of Learning studies concerning Learning study sustainability. Extra individual support may be unsustainable given the commitments of a Learning study facilitator/researcher or the participants themselves. Yet, as demonstrated in this study, the extra support might prove beneficial and essential for teachers to engage deeply and meaningfully with the Learning study discourse during challenging times. Future research should explore the degree of support required to meet teacher needs based on novel theoretical perspectives, more complex objects of learning, and differing models of Learning study. From these results, feasibility for other contexts can be ascertained.

In this research, online and in-person elements of a Learning study became necessary due to school-based COVID-19 restrictions. This area is significant given the potential of online learning environments to connect teachers across schools, districts, and countries and the rise in online- or mixed-teacher professional development (Yurkofsky et al., 2019). The affordances of online modalities provide ways for the teaching and learning experiences which support teacher learning offered by the Learning study to be extended. These areas deserve future research.

For example, many teacher attributes described in Chapter 5 are related to awareness and familiarity with SSI-specific knowledge and pedagogies. These could be further supported by focusing on contributions and collaboration between Learning study groups. For example, different issue-specific knowledge domains (e.g., around water eutrophication) could be shared through online management systems or direct conversations with teachers interested in the same SSIs and engaged in a different Learning study. Pedagogies conducive to approaching these knowledge domains given specific learning outcomes could be shared in similar fashions. These resources resemble Catherine Lewis' work and others in The Lesson Study Group at Mills College (e.g., The Lesson Study Group, 2022). They offer a compendium of Lesson study-developed resources by grade and subject.

Likewise, observations of Learning study research lessons could be shared with those interested in similar approaches, given appropriate ethical considerations. For example, the research lessons Nicole deemed successful in promoting her students' increased compassion for others affected by SSI could be shared with other educators looking to develop similar student capacities. Video-based lesson observations could then be followed by post-lesson conferences with the teacher who taught the research lesson. This could be attended by pre-service education students, as demonstrated by Widjaja et al. (2021), providing insights into the 'on the ground' interpretations of teaching practice by teachers. Understandably, the logistics of such endeavours could be large. However, greater collaboration between departments of education and local schools is often sought (Hargreaves, 2019). There are those teacher educators with strong connections to in-service teachers and professional development where these types of arrangements could be pursued (e.g., Calleja & Camilleri, 2021; Hrastinski, 2021; Suh et al., 2021; Widjaja et al., 2021). Importantly, teacher capacity and interest in these enrichments must be carefully considered. Justifiable and prudent collaboration between different Learning study groups, departments of education, and local schools is advocated here.

Related more broadly to SRSE and SSI-based science education approaches, these connections of interested educators, connected through online environments, could form an assemblage of pro-SRSE actants (i.e., what Bencze [2020], borrowing from Actor-Network-Theory [Latour, 2005] and Foucault [2008] might call a 'dispositif'). Collectively, they may have the capacity to envision new means and ends toward collective goals. As described above

(Section 6.3.3), common issues from diverse contexts may provide the most enriched learning and sharing. The 'catalyzing issue' of climate change takes on a new meaning here. Rather than only catalyzing interest in action, advocacy, and activism in different topics for one or a group of individuals, a ‘catalyzing issue’ could unite students, teachers, schools, and school systems in shared pursuits (i.e., breadth of SSI engagement versus depth) (Fuchs et al., in press). Research of this ilk could explore what factors promote or constrain these new assemblages of climate-conscious actants, for example, and what types of knowledge are shared between them. Staying with the idea of a 'catalyzing issue,’ how the actants of these assemblages then expand to other actants (e.g., schools to the community) would be of interest. In this case, the online ‘environment’ and issues explored can be conceptualized as the 'glue' (Bencze, 2020) between actants making up the pro-SRSE (or pro-environmental, etc.) assemblage or shared ideals.

6.3.5 Implications for Curriculum and Policy

An educational issue discussed in the introduction of this dissertation regarded the revised BC science curriculum (BCME, 2018a, 2018b). In many regards, it is poised to support SRSE practices (e.g., Blades, 2019; Fuchs & Tan, 2022). However, some recommendations are warranted, given the results of this work.

First, curriculum workers might consider including additional resources supporting each overarching goal and rationale of the revised science curriculum (BCME, 2018b). Currently, the support section of the science curriculum website contains four links. Two relate to physics formulas, one to science safety and one to instructional samples (BCME, 2022a). Six instructional samples exist, of which three are duplicates (BCME, 2022b): quarks and leptons, scientific inquiry, and ‘snow smarter’ (resources for making fake snow). Certainly, as teachers share resources, the Ministry of Education will add more to its website. Based on the results of this work, several types of resources might be prioritized if a goal is to support the SRSE-aligned components of the revised curriculum.

One could include a compendium of explicit SSI tied to curricular points that could be explored with local community or university organizations. In this work, Nicole's choice of COVID-19 as an SSI was undoubtedly (and unfortunately) timely. However, it was also an explicit point in the Grade 8 curriculum regarding pandemics and epidemics. Explicit, local issues might provide tangible starting points to engage in the varied SRSE practices outlined throughout this dissertation. This recommendation is supported by the extensive deliberations the teachers went through to choose SSIs most appropriate for their students, courses, and interests. The addition of community or university organizations interested in similar SSI (e.g., urban beekeeping [Kitsilano, 2017]; container framing [Leader, 2021]; salmon preservation [Pacific Salmon Foundation, 2023]; land-based learning [ILLP, 2023]) provides pathways teachers can leverage to explore SSI-specific knowledge domains and provide an opportunity for greater school-community collaboration. These relationships, in turn, may help to address critiques of action-oriented science education as the renewal and conservation of practices could be explored (e.g., Bowers, 2008) through a heightened understanding of issues in local contexts.

Like the balance between providing opportunities for action and allowing students autonomy in their choices, resources pointing to student groups interested in addressing SSI could also be presented (e.g., CERBC, 2023; Sustainabiliteens, 2023). These areas provide options for students to engage in action and provide teachers inspiration on how to set up and support their own community care projects. Of course, these resources would need to be dynamic as community and university projects change. This is where teacher associations or departments of education could be leveraged as resources to maintain current community, student, and university-based programs (e.g., EEPSA, 2023; ISABC, 2023). These recommendations provide starting points for educators to talk with one another, explore resources, and encounter new knowledge domains in line with the goals and rationale of the revised science curricula.

Based on the results of this study, ‘more’ resources may well aid teachers already interested in SRSE components of the curriculum. However, professional development is likely required for those needing more substantial support. Such programs should not just share the above resources uncritically. Rather, the resources should be used as mediums to interrogate educators' beliefs, place resources in practice situations, and reflect on student and teacher learning outcomes. Learning study serves as a suitable example of such professional development approaches. In that regard, more Learning studies could be conducted to support teachers in their SRSE goals and explore more cases of SRSE implementation. As collated and analyzed, these cases may further our understanding of the essential processes behind the uptake of curricular elements aligned with SRSE (cf. given the considerations in section 6.3.4.1)

Finally, elements of the revised curriculum the teachers in this study deemed essential for their SRSE exploration deserve attention. When pursuing SRSE, the teachers often relied on the competencies (i.e., skills and processes meant to be the foundation of the content) of the revised curriculum to enact their lessons. These can be seen in their chosen objects of learning. Rather than being ‘ignored,’ the enactment of the goals and rationale of the revised science curriculum proved well supported by the competencies. Likewise, the lack of a year-ending exam (Blades, 2019) proved advantageous to explore the new curriculum in ways that shifted practice. Though these high-stakes exams have some utility in standardizing educational outcomes, the ‘control’ they exhibit on teachers regarding pedagogy and knowledge domains is well documented (Au, 2007). As found in the BC curriculum, providing teachers with autonomy in assessment practices (Tidemand & Nielson, 2017) supported exploring SRSE-aligned goals.

6.4 Coda

Much of this dissertation explored tension. The tension between traditional science education goals and ones oriented toward critical sustainability was the most pronounced. Therein, context-specific pedagogical and curricular norms illuminated false dichotomies that pitted certain practices, aims, and beliefs of science education against one another. For a teacher of SRSE, tensions were numerous. Does one share values with students or keep them hidden for fear of student indoctrination? Does one teach ‘for’ high-stakes exams or explore broader skills and competencies? Does one force altruistic action or gestate autonomous choices? Does one forge ahead with personal goals for science education or acquiesce to the status quo?

Tensions for me as the professional development facilitator and researcher were related. Does one propose new ideas for ideocratic SRSE adoption or strongly suggest research-informed practices? Does one stick to pre-planned models and plans or capitulate fully to the context's needs? When a global pandemic changes the very nature of school-based work, does one wait for the return of normalcy or move ahead?

Ted Aoki teaches us that a tensionless string cannot sing (Aoki, 1986; Pinar & Irwin, 2005). Like the tuner and bridge of a guitar, the false dichotomies presented above anchor understanding for the creation of music. It is in this tension, in the oscillation between dichotomies, that their falsehood is realized. In the between space of two points, learning, growth, and discovery are created. From this between space, I offer some concluding thoughts on fruitfully dwelling – or 'singing' – in the tensions of this work.

Uncovering ways false dichotomies can be exposed and negotiated appear beneficial to continued SRSE exploration. The tensions I'm most drawn to after writing about this work concern those inherent in starting and supporting SRSE. Oscar Hammerstein II, writing for *The Sound of Music,* provides guidance on where to begin.

Let's start at the very beginning
A very good place to start
- Oscar Hammerstein II

There is diminishing value in socially responsible science education without an envisioned future to be responsible for. Should this future be prudent, ethical, and wise, it ought to be pursued. The tensions arising from how that pursuit is realized gives new understandings to negotiated and nuanced uptake. However, students will ultimately inhabit the future SRSE seeks to produce. To start at the very beginning is to honour student interest, drive, and passion. To 'begin,' is to begin with young people in mind while interweaving the support of caring adults.

For students of SRSE, this means they should bring altruistic interests, desires, and plans to science classrooms and spaces. These interests can often be paired with curriculum originating from outside sources to enhance its learning potential (Aoki, 1986). However, this takes a willingness by the teacher. For teachers of SRSE, this means students need to feel safe and supported in bringing issues they care about into schools, and particularly science classrooms. A relatively easy way to achieve this is by teachers bringing issues they care about into classrooms. This explicit modelling condones certain behaviours that students can build from.

From there, classroom-based and co-curricular initiatives can run a range of structured and unstructured orientations, such as inquiry projects, prolonged conversations, or student clubs. These areas can be co-created as opportunities to explore and even realize envisioned futures along SRSE. They could even be used to vote on issue exploration in the first place.

What is ultimately ‘done’ with the issue depends on the context in which it is explored. However, it is in considering it in the first place that makes it a very good place to start.

Legacy. What is a legacy?
It’s planting seeds in a garden you never get to see.
- Lin-Manual Miranda

Pursuing SRSE is not easy, and the legacy of SRSE initiatives are difficult to ascertain. Research into the longevity and formation of pro-environmental and social behaviours spans philosophical and methodological traditions, appearing to depend as much on worldview, upbringing, and identity as modifiable or embodied characteristics. To that end, the 'seeds' of SRSE as planted and nurtured may not produce the results initially intended.

It is apparent that students, teachers, and researchers cannot force the pursuit of SRSE they deem most appropriate on others. The practical implications of this stance, let alone the moral and ethical, remained a tension throughout this work. However, what can be done is to make the conditions for SRSE as fertile as possible. Above, student- or teacher-led issue exploration is one 'fertilizer' for such SRSE plots. The concurrent-and-successive Learning study model is another. Its broad focus on the reflection on beliefs, their sharing, and application in classroom research appears particularly powerful to explore and resolve several SRSE tensions.

For me, ‘catalyzing issues’ are an intriguing concept that might act as ways into SRSE and lead to differential SSI exploration, both in terms of breadth (‘what’ is explored) and depth (levels of injustice and what can be done about them). These issues may act as the first 'strum,' 'pluck,' or 'hit' of an SRSE tension that begins to uncover its anchor points. Upon continued 'singing,' new tensions arise and resonate. With each resonance, new notes fill pages, new insights gain harmony, and ‘dwelling within’ (Aoki, 1986) is underway. If I were to recommend a path from here, it would be to let that dwelling continue. Let the tension sing.

References

Abd-El-Khalick,F., Bell, R. L., & Lederman, N.G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*(4), 417–436. https://doi.org/10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.0.CO;2-E

Abd-El-Khalick, F., & Lederman, N. G. (2000a). The influence of history of science courses on students views of nature of science. *Journal of Research in Science Teaching, 37*(10), 1057–1095. https://doi.org/10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., & Lederman, N. G. (2000b). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665–701. https://doi.org/10.1080/09500690050044044

Aikenhead, G. S. (1994). What is STS teaching? In J. A. Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 47–59). Teachers College Press. https://doi.org/10.4324/9780203006436-5

Aikenhead, G. S. (2006). *Science education for everyday life: Evidence-based practice*. Teachers College Press.

Aikenhead, G. S. (2007). Expanding the research agenda for scientific literacy. In C. Linder, L. Östman, & P. Wickman (Eds.), *Proceedings of the Linnaeus tercentenary symposium on promoting scientific literacy: Science education research in transaction* (pp. 64–72). Uppsala, Sweden: Uppsala University.

Aikenhead, G. S. (2023). Humanistic school science: Research, policy, politics and classrooms. *Science Education*, *107*(2), 237–260. https://doi.org/10.1002/sce.21774

Akerson, V. L., Pongsanon, K., Park Rogers, M. A., Carter, I., & Galindo, E. (2017). Exploring the use of lesson study to develop elementary preservice teachers' pedagogical content knowledge for teaching nature of science. *International Journal of Science and Mathematics Education*, *15*(2), 293–312. https://doi.org/10.1007/s10763-015-9690-x

Åkerlind, G. S. (2004). A new dimension to understanding university teaching. *Teaching in Higher Education*, *9*(3), 363–375. https://doi.org/10.1080/1356251042000216679

Åkerlind, G. (2005). Learning about phenomenography: Interviewing, data analysis and the qualitative research paradigm. In J. Bowden (Ed.), *Doing developmental phenomenography* (pp. 63–74). RMIT University Press.

Åkerlind, G. S. (2012). Variation and commonality in phenomenographic research methods. *Higher Education Research & Development*, *31*(1), 115–127. https://doi.org/10.1080/07294360.2011.642845

Åkerlind, G. (2018). What future for phenomenographic research? On continuity and development in the phenomenography and variation theory research tradition. *Scandinavian Journal of Education Research, 62*(6), 949–958. https://doi.org/10.1080/00313831.2017.1324899

Åkerlind, G.S., Bowden, J., & Green, P. (2005). Learning to do phenomenography: A reflective discussion. In J. Bowden & P. Green (Eds.), *Doing developmental phenomenography* (pp. 74–100). RMIT University Press.

Amos, R., Knippels, M.-C., & Levinson, R. (2020). Socio-scientific inquiry-based learning: Possibilities, and challenges for teacher education. In M. Evagorou, J.A. Nielsen & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 41–61). Springer. https://doi.org/10.1007/978-3-030-40229-7_4

Anderberg, E., Svensson, L., Alvegård, C., & Johansson, T. (2008). The epistemological role of language use in learning: A phenomenographic intentional-expressive approach. *Educational Research Review*, *3*(1), 14–29. https://doi.org/10.1016/j.edurev.2007.10.003

Aoki, T. (1986). Teaching as Indwelling Between Two Curriculum Worlds. *The B.C. Teacher, 65* (3), April/May.

Arsenault, M. R. (1987). *Male competition and reproductive behaviour of the crayfish Orconectes rusticus during springtime*. Trent University.

Ashworth, P., & Lucas, U. (2000). Achieving empathy and engagement: A practical approach to the design, conduct and reporting of phenomenographic research. *Studies in higher Education*, *25*(3), 295–308. https://doi.org/10.1080/713696153

Attorps, I., & Kellner, E. (2017). School–university action research: Impacts on teaching practices and pupil learning. *International Journal of Science and Mathematics Education, 15* (2), 313–330. https://doi.org/10.1007/s10763-015-9686-6

Avidov-Ungar, O., & Konkes Ben Zion, R. (2019). The characteristics and perceptions of teachers engaged in leading professional communities. *Teacher Development*, *23*(3), 325–344. https://doi.org/10.1080/13664530.2019.1607772

Au, W. (2007). High-stakes testing and curricular control: A qualitative metasynthesis. *Educational researcher*, *36*(5), 258–267. https://doi.org/10.3102/0013189X07306523

Australian Curriculum, Assessment and Reporting Authority (ACARA). (2012). *The Australian curriculum: science*. Australia: Australian Curriculum, Assessment and Reporting Authority. https://www.australiancurriculum.edu.au/f-10-curriculum/science/rationale/

Ayala, G., & Spieldenner, A. (2021). HIV Is a Story First Written on the Bodies of Gay and Bisexual Men. *American Journal of Public Health*, *111*(7), 1240–1242. https://doi.org/10.2105/AJPH.2021.306348

Babai, R. & Amsterdamer, A. (2008). The persistence of solid and liquid naive conceptions: a reaction time study. *Journal of Science Education and Technology, 17,* 553–559. https://doi.org/10.1007/s10956-008-9122-6

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

Bencze, J. L. (Ed.) (2017). *Science & technology education promoting wellbeing for individuals, societies & environments.* Springer. https://doi.org/10.1007/978-3-319-55505-8

Bencze, J.L. (2020). Re-visioning ideological assemblages through de-punctualizing and activist science, mathematics & technology education. *Canadian Journal of Science, Mathematics & Technology Education, 20*(4), 736–749. https://doi.org/10.1007/s42330-020-00133-3

Bencze, J. L., & Alsop, S. (2009). A critical and creative inquiry into school science inquiry. In W.-M. Roth & K. Tobin (Eds.), *World of science education: North America* (pp. 27–47). Sense. https://doi.org/10.1163/9789087907471_005

Bencze, L., Bowen, M., & Alsop, S. (2006). Teachers' tendencies to promote student-led science projects: Associations with their views about science. *Science Education, 90*(3), 400–419. https://doi.org/10.1002/sce.20124

Bencze, L., & Carter, L. (2011). Globalizing students acting for the common good. *Journal of Research in Science Teaching*, *48*(6), 648–669. https://doi.org/10.1002/tea.20419

Bencze, L., & Hodson, D. (1999). Changing practice by changing practice: Toward more authentic science and science curriculum development. *Journal of Research in Science Teaching, 36*(5), 521–539. https://doi.org/10.1002/(SICI)1098-2736(199905)36:5<521::AID-TEA2>3.0.CO;2-6

Bencze, L. & Krstovic, M. (2017). Resisting the borg: Science teaching for common wellbeing. In L. Bencze (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 227–276). Springer. https://doi.org/10.1007/978-3-319-55505-8_11

Bencze, L., Reiss, M., Sharma, A., & Weinstein, M. (2018). STEM education as 'Trojan horse': Deconstructed and reinvented for all. In L. Bryan, & K. Tobin (Eds.), *Thirteen questions in science education* (pp. 69–87). Peter Lang. https://doi.org/10.3726/b11305

Bencze, L., Pouliot, C., Pedretti, E., Simonneaux, L., Simonneaux, J., & Zeidler, D. (2020). SAQ, SSI and STSE education: Defending and extending 'science-in-context'. *Cultural Studies of Science Education, 15*(3), 825–851. https://doi.org/10.1007/s11422-019-09962-7

Bennett, J., & Hogarth, S. (2009). Would you want to talk to a scientist at a party? High school students' attitudes to school science and to science. *International Journal of Science Education, 31*, 1975–1998. https://doi.org/10.1080/09500690802425581

Berglund, A. (2005). *Learning computer systems in a distributed project course* [Doctoral dissertation, Universitatas Upsaliensis]. http://uu.diva-portal.org/smash/record.jsf?pid=diva2%3A166270&dswid=2820

Bernal, J.D. (1949). *The freedom of necessity*. Routledge and Kegan Paul.

Björk, M. (2019). Transforming a practice-based problem into research questions. *International Journal for Lesson and Learning Studies*, *8*(3), 244–255. https://doi.org/10.1108/IJLLS-08-2018-0059

Björkholm, E. (2014). Exploring the capability of evaluating technical solutions: a collaborative study into the primary technology classroom. *International Journal of Technology and Design Education, 24*(1), 1–18. https://doi.org/10.1007/s10798-013-9240-1

Blades, D. (2019). Science Education in British Columbia: A New Curriculum for the 21st Century. In C. Tippett & T. Milford (Eds.), *Science Education in Canada* (pp. 13–36). Springer International. https://doi.org/10.1007/978-3-030-06191-3_2

Bigloo, F., Scott, S., & Adler, D. (2021). Understanding curriculum as geo/biospheric text. *Prospects*, *51*(1-3), 117–128. https://doi.org/10.1007/s11125-021-09553-x

Booth, S. (1997). On phenomenography, learning and teaching. *Higher Education Research & Development, 16*(2), 135–158. https://doi.org/10.1080/0729436970160203

Booth, S., Hultén, M. (2003). Opening dimensions of variation: An empirical study of learning in a Web-based discussion. *Instructional Science, 31*, 65–86. https://doi.org/10.1023/A:1022552301050

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15. https://doi.org/10.3102/0013189X033008003

Boulton-Lewis, G. M., Smith, D. J. H., McCrindle, A. R., Burnett, P.C., & Campbell, K. J. (2001). Secondary teachers' conceptions of teaching and learning. *Learning and Instruction, 11*, 35–51. https://doi.org/10.1016/S0959-4752(00)00014-1

Boudreau, C., MacKenzie, S. A., & Simmons, D. J. (2022). Police Violence and Public Opinion After George Floyd: How the Black Lives Matter Movement and Endorsements Affect Support for Reforms. *Political Research Quarterly*, *75*(2), 497–511. https://doi.org/10.1177/10659129221081007

Bowden, J. A. (1994a). The nature of phenomenographic research. In J. A. Bowden & E. Walsh (Eds.), *Phenomenographic research: Variations in method*. The Warburton symposium (pp. 1–16). Royal Melbourne Institute of Technology.

Bowden, J. A. (1994b). Phenomenographic research: a personal experience. In J. A. Bowden & E. Walsh (Eds.), *Phenomenographic research: Variations in method*. The Warburton symposium (pp. 43–55). Royal Melbourne Institute of Technology.

Bowden, J., & Green, P. (Eds.). (2005). *Doing developmental phenomenography*. RMIT University Press.

Bowden, J. A., & Walsh, E. (Eds.). (1994). *Phenomenographic research: Variations in method*. Royal Melbourne Institute of Technology

Bowe, J., & Gore, J. (2017). Reassembling teacher professional development: The case for Quality Teaching Rounds. *Teachers and Teaching*, *23*(3), 352–366. https://doi.org/10.1080/13540602.2016.1206522

Bowen, L. (2020). Time to talk about teaching: The power of quality teaching rounds. *Jounral of Professional Learning, Semester 1,* 2020. https://cpl.nswtf.org.au/journal/semester-1-2020/time-to-talk-about-teaching-the-power-of-quality-teaching-rounds/

Bowers, C. (2008). Why a critical pedagogy of place is an oxymoron. *Environmental Education Research, 14*(3), 325–335. https://doi.org/10.1080/13504620802156470

Bravo, P., & Cofré, H. (2016). Developing biology teachers' pedagogical content knowledge through learning study: the case of teaching human evolution. *International Journal of Science Education*, *38*(16), 2500–2527. https://doi.org/10.1080/09500693.2016.1249983

British Columbia Ministry of Education [BCME]. (2011). BC's education plan. https://buildingpublicunderstanding.org/assets/files/pubstory/bc_edu_plan.pdf

British Columbia Ministry of Education [BCME]. (2018a). Science K-12: Rationale. https://curriculum.gov.bc.ca/curriculum/science/core/goals-and-rationale

British Columbia Ministry of Education [BCME]. (2018b). Classroom assessment and reporting. https://curriculum.gov.bc.ca/assessment/classroom-assessment-and-reporting

British Columbia Ministry of Education [BCME]. (2018c). Chemistry 11. https://curriculum.gov.bc.ca/curriculum/science/11/chemistry

British Columbia Ministry of Education [BCME]. (2022a). Science: Getting started. https://curriculum.gov.bc.ca/curriculum/science

British Columbia Ministry of Education [BCME]. (2022b). Instructional Samples: Science. https://curriculum.gov.bc.ca/instructional-samples?field_subject_range_value=Science

British Columbia Science Teacher Science Teachers Association [BCsTA]. (2023). Catalyst Conference. https://bcscta.com/bcscta-catalyst-conference/

Brown, A.L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178. https://doi.org/10.1207/s15327809jls0202_2

Bruce, C. D., Flynn, T. C., & Bennett, S. (2016). A focus on exploratory tasks in lesson study: The Canadian 'Math for Young Children' project. *ZDM*, *48*(4), 541–554. https://doi.org/10.1007/s11858-015-0747-7

Burek, K., & Zeidler, D. L. (2015). Seeing the forest for the trees! Conservation and activism through socioscientific issues. In M.P. Muller & D. J. Tippins (Eds.), *EcoJustice, citizen science and youth activism* (pp. 425–441). Springer, Cham. https://doi.org/10.1007/978-3-319-11608-2_26

Buxton, C. A. (2010). Social problem solving through science: An approach to critical, place-based, science teaching and learning. *Equity & Excellence in Education*, *43*(1), 120–135. https://doi.org/10.1080/10665680903408932

Bybee, R. (2006). Scientific inquiry and science teaching. In L.B. Flick & N.G. Lederman (Eds.), *Scientific Inquiry and Nature of Science* (pp. 1–14). Springer. https://doi.org/10.1007/978-1-4020-5814-1_1

Campbell, C., MacPherson, S., & Sawkins, T. (2014). Preparing students for education, work, and community: Activity theory in task-based curriculum design. *TESL Canada Journal*, 68–68. https://doi.org/10.18806/tesl.v31i0.1187

Calleja, J., & Camilleri, P. (2021). Teachers' learning in extraordinary times: shifting to a digitally facilitated approach to lesson study. *International Journal for Lesson and Learning Studies, 10*(2), 118–137. https://doi.org/10.1108/IJLLS-09-2020-0058

Can, Ö. K., Lane, J. F., & Ateşkan, A. (2017). Facilitating place-based environmental education through bird studies: An action research investigation. *Environmental Education Research*, *23*(5), 733–747. https://doi.org/10.1080/13504622.2016.1233389

Carney, M. (2021). *Value(s): Building a better world for all.* Penguin Random House Canada.

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review*, *32*, 100377. https://doi.org/10.1016/j.edurev.2020.100377

Cheung, W. M., & Wong, W. Y. (2014). Does Lesson Study work?: A systematic review on the effects of Lesson Study and Learning Study on teachers and students. *International Journal for Lesson and Learning Studies*, *3*(2), 137–149. https://doi.org/10.1108/IJLLS-05-2013-0024

Christensen, S. S., Davies, R. S., Harris, S. P., Hanks, J., & Bowles, B. (2019). Teacher recruitment: Factors that predict high school students' willingness to become teachers. *Education Sciences, 9*(4), 282–291. https://doi.org/10.3390/educsci9040282

Chung, Y., Yoo, J., Kim, S-W., Lee, H. & Zeidler, D.L. (2016). Enhancing students' communication skills in the science classroom through socioscientific issues. *International Journal of Science and Mathematics Education, 14*(1), 1–27. https://doi.org/10.1007/s10763-014-9557-6

Clarke, A. (1998). Born of incidents but thematic in nature: Knowledge construction in practicum settings. *Canadian Journal of Education/Revue canadienne de l'education*, 47–62. https://doi.org/10.2307/1585965

Clark, A. & Erickson, G. (2006). Teacher inquiry: What's old is new again. *BC Educational Leadership Research, 6*, 1–8. https://blogs.ubc.ca/stevemcg/files/2015/09/Clarke-Erickson-2006.-Teacher-inquiry-Whats-old-is-new-again.pdf

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947–967. https://doi.org/10.1016/S0742-051X(02)00053-7

Climate Education Reform BC [CERBC]. (2023). Reform to transform. https://www.climateeducationreformbc.ca/

Cochran, K.F., DeRuiter, J.A. & King, R.A. (1993). Pedagogical content knowledge: An integrative model for teacher preparation. *Journal of Teacher Education, 44,* 263–272. https://doi.org/10.1177/0022487193044004004

Coghlan, D., & Shani, A. B. R. (2005). Roles, politics, and ethics in action research design. *Systemic Practice and Action Research, 18*(6), 533–546. https://doi.org/10.1007/s11213-005-9465-3

Collier-Reed, B. I. (2006). *Pupils' experiences of technology: Exploring dimensions of technological literacy* [Doctoral dissertation, University of Cape Town]. Open UCT.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O' Shea (Eds), *New Directions in Educational Technology* (pp. 15–22). Springer. https://doi.org/10.1007/978-3-642-77750-9_2

Collins, A. (1999). The changing infrastructure of educational research. In A. Lagemann & L. Shulman (Eds.), *Issues in Educational Research*. Joss

Conrad, J., & Mitchell, D. (2022, December 21). B.C. is right to take on Telus Health for putting family doctors behind a paywall. Vancouver *Sun*. https://vancouversun.com/

Cooper, S., Wilkerson, T. L., Eddy, C. M., Kamen, M., Marble, S., Junk, D., & Sawyer, C. (2011). Lesson study among mathematics educators: Professional collaboration enabled through a virtual faculty learning community. *Learning Communities Journal*, *3*(1), 21–40.

Cope, C. J. (2002). Educationally critical aspects of the concept of an information system. *Informing Science Journal, 5*, 67–78. https://doi.org/10.28945/538

Cope, C. (2004). Ensuring validity and reliability in phenomenographic research using the analytical framework of a structure of awareness. *Qualitative Research Journal, 4*(2), 5–18.

Council of Ministers of Education, Canada (CMEC). (1997). *Common framework of science learning outcomes, K-12: Pan-Canadian protocol for collaboration on school curriculum.* Toronto, ON: Council of Ministers of Education, Canada. http://204.225.6.243/science/framework/pages/english/cmec%20eng.html.

Creswell, J.W. (1994). *Research design: Qualitative and quantitative approaches.* Sage

Green, E. L. (2021). Black lives matter, she wrote. Then ‘everything just imploded.’. *The New York Times*. http://www.kooriweb.org/foley/news/2000s/2021/oct/nyt10oct2021.pdf

Cross, R. T., & Price, R. F. (1991). Towards teaching science for social responsibility: an examination of flaws in science, technology and society. *Research in Science Education*, *21*(1), 47–54. https://doi.org/10.1007/BF02360456

Cross, R.T. & Price, R.F. (1996). Science teachers' social conscience and the role of controversial issues in the teaching of science. *Journal of Research in Science Teaching, 33*, 319–333. https://doi.org/10.1002/(SICI)1098-2736(199603)33:3<319::AID-TEA5>3.0.CO;2-W

Cross, R. T., & Price, R. F. (1999). The social responsibility of science and the public understanding of science. *International Journal of Science Education*, *21*(7), 775–785. https://doi.org/10.1080/095006999290435

Dahlin, B. (2007). Enriching the theoretical horizons of phenomenography, variation theory and learning studies. *Scandinavian Journal of Educational Research*, *51*(4), 327–346. https://doi.org/10.1080/00313830701485437

Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2019). Creating a continuum of STEM models: Exploring how K-12 science teachers conceptualize STEM education. *International Journal of Science Education*, *41*(12), 1701–1720. https://doi.org/10.1080/09500693.2019.1638531

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan, 76*(8), 597–604. https://doi.org/10.1177/003172171109200622

Dawes, L. (2017). Faculty perceptions of teaching information literacy to first-year students: A phenomenographic study. *Journal of Librarianship and Information Science*, *51*(2), 545–560. https://doi.org/10.1177/0961000617726129

De Beer, J. (2019). Cultural-Historical Activity Theory (CHAT) as a Practical Lens to Guide Classroom Action Research in the Biology Classroom. *The American Biology Teacher*, *81*(6), 395-402. https://doi.org/10.1525/abt.2019.81.6.395

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

Derr, V. (2020). Diverse perspectives on action for positive social and environmental change. *Environmental Education Research, 26*(2), 219–237. https://doi.org/10.1080/13504622.2020.1715925

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Desimone, L. M., & Stuckey, D. (2014). Sustaining teacher professional development. In L. E. Martin, S. Kragler, D. J. Quatroche, & K. L. Bauserman (Eds.), *Handbook of Professional Development in Education: Successful Models and Practices, PreK–12* (pp. 467–482). Guilford Publications.

Di Pietro, G., Biagi, F., Costa, P., Karpinski, Z. and Mazza, J. (2020). *The Likely Impact of COVID-19 on Education: Reflections Based on the Existing Literature and International Datasets*. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC121071

Doig, B., & Groves, S. (2011). Japanese lesson study: Teacher professional development through communities of inquiry. *Mathematics Teacher Education and Development*, *13*(1), 77–93. https://files.eric.ed.gov/fulltext/EJ960950.pdf

Donnelly, J. F. (2004). Humanizing science education. *Science Education, 88*, 762–784. https://doi.org/10.1002/sce.20004

Dos Santos, W. L. P. (2009). Scientific literacy: A Freirean perspective as a radical view of humanistic science education. *Science Education, 93*(2), 361–382. https://doi.org/10.1002/sce.20301

Dwyer, S. C., & Buckle, J. L. (2009). The space between: On being an insider-outsider in qualitative research. *International Journal of Qualitative Methods*, *8*(1), 54–63. https://doi.org/10.1177/160940690900800105

Earth Day. (2023). Earth Day Every Day. https://www.earthday.org/

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education, 34*(15), 2289–2315. https://doi.org/10.1080/09500693.2012.667582

Eisner, E. (1985). The three curricula that all schools teach. In E. Eisner (Ed.), *The educational imagination* (pp. 87–108). Macmillan.

El Halwany, S., Zouda, M., & Bencze, J. L. (2021). Stepping into STS literature: Some implications for promoting socioecological justice through science education. *Cultural Studies of Science Education*, *16*(4), 1083–1096. https://doi.org/10.1007/s11422-021-10026-y

Elliott, J. (2012). Developing a science of teaching through lesson study. *International Journal for Lesson and Learning Studies, 1*(2), 108–125. https://doi.org/10.1108/20468251211224163

Elliott, J. (2015) Educational action research as the quest for virtue in teaching. *Educational Action Research, 23*(1), 4–21. https://doi.org/10.1080/09650792.2014.994017

Elliott, J. (2019). A Western perspective. In R. Huang, A. Takahashi, J. A. Ponte (Eds.), *Theory and practice of lesson study in mathematics: An international perspective* (pp. 789–801). Springer Nature. https://doi.org/10.1007/978-3-030-04031-4_37

Elmore, R.F. (2002). *Bridging the gap between standards and achievement: the imperative for professional development in education.* The Albert Shanker Institute. https://www.shankerinstitute.org/resource/bridging-gap-between-standards-and-achievement

Endreny, A. H. (2010). Urban 5th graders conceptions during a place-based inquiry unit on watersheds. *Journal of Research in Science Teaching, 47*(5), 501–517. https://doi.org/10.1002/tea.20348

Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research.* Orienta-Konsultit.

Engeström, Y. (1999). Expansive visibilization of work: An activity-theoretical perspective. *Computer Supported Cooperative Work: The Journal of Collaborative Computing, 9*(1–2), 63–93. https://doi.org/10.1023/A:1008648532192

Engeström, Y. (2001). Expansive learning at work: Toward an activity-theoretical perspective. *Journal of Education and Work, 14*(1), 133–156. https://doi.org/10.1080/13639080020028747

Engeström, Y. (2009). Expansive learning: Toward an activity-theoretical reconceptualization. In K. Illeris (Ed.), *Contemporary theories of learning* (pp. 53–73). Routledge.

Engeström, Y. (2017). Expanding the scope of science education: an activity-theoretical perspective. In K. Hahl, K. Juuti, J. Lampiselkä, A. Uitto & J. Lavonen (Eds.). *Cognitive and affective aspects in science education research* (pp. 357–370). Springer, Cham. https://doi.org/10.1007/978-3-319-58685-4_26

Entwistle, N. (1997). Introduction: Phenomenography in higher education. *Higher Education Research & Development, 16*, 127–134. https://doi.org/10.1080/0729436970160202

Environmental Educators Provincial Specialist Association [EEPSA]. (2023). Local chapters of EEPSA. https://eepsa.org/local-chapters-eepsa/

Eva, K. W. (2008). On the limits of systematicity. *Medical Education*, *42*(9), 852–853. https://doi.org/10.1111/j.1365-2923.2008.03140.x

Evagorou, M. & Puig Mauriz, B. (2017). Engaging elementary school pre-service teachers in modelling a socioscientific issue as a way to help them appreciate the social aspects of science**.** *International Journal of Education in Mathematics, Science and Technology, 5*(2), 113–123. https://doi.org/10.18404/ijemst.99074

Evagorou, M., Nielsen, J. A., & Dillon, J. (2020). *Science Teacher Education for Responsible Citizenship: Towards a Pedagogy for Relevance Through Socioscientific Issues*. Springer. https://doi.org/10.1007/978-3-030-40229-7

Fazio, X. (2009). Development of a community of science teachers: Participation in a collaborative action research project. *School Science and Mathematics*, *109*(2), 95–107. https://doi.org/10.1111/j.1949-8594.2009.tb17942.x

Fazio, X., & Melville, W. (2008). Science teacher development through collaborative action research. *Teacher Development*, *12*(3), 193–209. https://doi.org/10.1080/13664530802259222

Fensham, P. (2002). Time to change drivers for scientific literacy. *Canadian Journal of Science, Technology and Mathematics Education, 2*, 9–24. https://doi.org/10.1080/14926150209556494

Fenstermacher, G. D. (1979). A philosophical consideration of recent research on teacher effectiveness. In L. S. Shulman (Eds.), *Review of Research in Education* (Vol. 6, pp. 157–185). Peacock. https://doi.org/10.3102/0091732X006001157

Foucault, M. (2008). The birth of biopolitics: Lectures at the Collège de France 1978-1979 (Ed.: Michael Sennelart; General Editors: Francois Ewald and Alessandro Fontana; Trans.: Graham Burchell). Palgrave Macmillan.

Francis, H. (1993). Advancing phenomenography: Questions of method. *Nordisk Pedagogik*, *13*(2), 68–75.

Fraser, D., & Linder, C. (2009). Teaching in higher education through the use of variation: Examples from distillation, physics and process dynamics. *European Journal of Engineering Education*, *34*(4), 369–381. https://doi.org/10.1080/03043790902989507

Fuchs, T. (2013). Effects of habitat complexity on invertebrate biodiversity. *Immediate Science Ecology, 2,* 1–10. https://ojs.library.queensu.ca/index.php/ISE/article/view/4627

Fuchs, T. (2016). LGBTQ inclusivity in the science classroom. *Canadian Teacher Magazine, Jan/Feb,* 6. http://www.canadianteachermagazine.com/issues/2016/CTM_JanFeb16/docs/CTM_JanFeb16_web.pdf

Fuchs, T. (2018). Compositional tinkering in the music room. *Ottiya Magazine: Meaningful, Creative, and Fun Learning & Education, 2,* 74–81. https://www.ottiya.com/magazine/2/compositional-tinkering-in-the-music-room/

Fuchs, T. (2019). Dwelling between curriculum-as-planned and curriculum-as-lived in science class. *Canadian Teacher Magazine, Winter,* 18–19. https://canadianteachermagazine.com/2019/01/19/dwelling-between-curriculum-as-planned-and-curriculum-as-lived-in-science-class/

Fuchs, T. T. (2023). A framework for climate change education in critical geography. *Geography, 108*(2), 95–100. https://doi.org/10.1080/00167487.2023.2217632

Fuchs, T. T., & Arsenault, M. (2017). Using test data to find misconceptions in secondary science. *School Science Review, 98*(364), 31–36. https://www.ase.org.uk/resources/school-science-review/issue-364/using-test-data-find-misconceptions-secondary-science

Fuchs, T. T., & Arsenault, M. (2018). *Secondary biology misconceptions: Using 23 years of test-data to inform pedagogy*. Conference proceedings of the National Association of Biology Teachers Professional Development Conference, 10th Annual NABT Biology Education Research Symposium, San Diego, USA. https://nabt.org/files/galleries/Fuchs_Arsenault.pdf

Fuchs, T. T., Bonney, K. M., & Arsenault, M. (2021). Leveraging Student Misconceptions to Improve Teaching of Biochemistry & Cell Biology. *The American Biology Teacher*, *83*(1), 5–11. https://doi.org/10.1525/abt.2021.83.1.5

Fuchs, T. T., Sadler, P. M., & Sonnert, G. (2015). High school predictors of a career in medicine. *Journal of Career and Technical Education*, *30*(1), 9–28. https://doi.org/10.21061/jcte.v30i1.711

Fuchs, T.T., Sonnert, G., Scott, S.A., Sadler, P.M., & Chen, C. (2022). Preparation and Motivation of High School Students Who Want to Become Science or Mathematics Teachers. *Journal of Science Teacher Education*, *33*(1), 83–106. https://doi.org/10.1080/1046560X.2021.1908658

Fuchs, T.T., Roppel, S., Harding, T., Erickson, H. (in press). Focus on the future: The development, implementation, and efficacy of teachers' climate change professional development. In J.L. Bencze (Ed), *Mobilizing critical and altruistic science education: Diversifying and broadening alliances for ecojustice.* Springer Nature

Fuchs, T. T., & Tan, Y. S. M. (2022). Frameworks supporting socially responsible science education: opportunities, challenges, and implementation. *Canadian Journal of Science, Mathematics and Technology Education*, *22*(1), 9–27. https://doi.org/10.1007/s42330-022-00200-x

Fujii, T. (2018). Lesson study and teaching mathematics through problem solving: The two wheels of a cart. In M. Quaresma, C. Winsløw, S. Clivaz, J. da Ponte, A. Ní Shúilleabháin, & A. Takahashi (Eds.), *Mathematics lesson study around the world* (pp. 1–21). Springer. https://doi.org/10.1007/978-3-319-75696-7_1

Fullan, M. (2011). *Change leader: Learning to do what matters most*. Jossey-Bass

Fuller, M. T., Dadoo, O., Xiong, T., Chivukula, P., MacDonald, M. E., Lee, S. K., ... & Trigatti, B. L. (2023). Extensive diet-induced atherosclerosis in scavenger receptor class B type 1-deficient mice is associated with substantial leukocytosis and elevated vascular cell adhesion molecule-1 expression in coronary artery endothelium. *Frontiers in Physiology*, *13*, 2747. https://doi.org/10.3389/fphys.2022.1023397

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

Gardner Burt, K. (2016). A complete history of the social, health, and political context of the school gardening movement in the United States: 1840–2014. *Journal of Hunger & Environmental Nutrition*, *11*(3), 297–316. https://doi.org/10.1080/19320248.2016.1157542

Gaskell, P. J. (1982). Science education for citizens: Perspectives and issues I. Science, technology and society: Issues for science teachers. *Studies in Science Education, 9,* 33–46. https://doi.org/10.1080/03057268208559894

Gentles, J. Q., Chen, L., & Hwang, H. (2021). Introducing oncoplastic breast surgery in a community hospital. *Canadian Journal of Surgery*, *64*(6), E654. https://doi.org/10.1503/cjs.009820

Gist, C. D., Bianco, M., & Lynn, M. (2019). Examining grow your own programs across the teacher development continuum: Mining research on teachers of color and non-traditional educator pipelines. *Journal of Teacher Education, 70*(1), 13–25. https://doi.org/10.1177/0022487118787504

Go, L., & Pang, M. F. (2021). Phenomenography in the "Lived" Context of Parental Learning. *International Journal of Qualitative Methods*, *20*, 1–10. https://doi.org/10.1177/16094069211016160

Goei, S.L., van Joolingen, W.R., Goettsch, F., Khaled, A., Coenen, T., In't Veld, S.G.J.G., de Vries, S. & Schipper, T.M. (2021). Online lesson study: virtual teaming in a new normal. *International Journal for Lesson and Learning Studies, 10*(2), 217–229. https://doi.org/10.1108/IJLLS-09-2020-0078

Gore, J., Barron, R. J., Holmes, K., & Smith, M. (2016). Who says we are not attracting the best and brightest? Teacher selection and the aspirations of Australian school students. *The Australian Educational Researcher, 43*(5), 527–549. https://doi.org/10.1007/s13384-016-0221-8

Gore, J., Holmes, K., Smith, M., Fray, L., McElduff, P., Weaver, N., & Wallington, C. (2017). Unpacking the career aspirations of Australian school students: Towards an evidence base for university equity initiatives in schools. *Higher Education Research & Development, 36*(7), 1383–1400. https://doi.org/10.1080/07294360.2017.1325847

Gore, J., Lloyd, A., Smith, M., Bowe, J., Ellis, H., & Lubans, D. (2017). Effects of professional development on the quality of teaching: Results from a randomised controlled trial of Quality Teaching Rounds. *Teaching and Teacher Education*, *68*, 99–113. https://doi.org/10.1016/j.tate.2017.08.007

Government of Canada (GoC). (2019). Canada's action on climate change. https://www.canada.ca/en/services/environment/weather/climatechange/climate-action.html

Granger, E. M., Bevis, T. H., Southerland, S. A., Saka, Y., & Ke, F. (2019). Examining features of how professional development and enactment of educative curricula influences elementary science teacher learning. *Journal of Research in Science Teaching*, *56*(3), 348–370. https://doi.org/10.1002/tea.21480

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Grau, V., Calcagni, E., Preiss, D. D., & Ortiz, D. (2017). Teachers' professional development through university–school partnerships: Theoretical standpoints and evidence from two pilot studies in Chile. *Cambridge Journal of Education*, *47*(1), 19–36. https://doi.org/10.1080/0305764X.2015.1102867

Gray, D. S., & Bryce, T. (2006). Socio-scientific issues in science education: implications for the professional development of teachers. *Cambridge Journal of Education*, *36*(2), 171–192. https://doi.org/10.1080/03057640600718489

Greenwood, D. J., & Levin, M. (1998). *Introduction to action research: Social research for social change.* Sage Publications.

Grady, J. (2010). The inquiry matrix: A tool for assessing and planning inquiry in biology and beyond. *The Science Teacher*, November, 32–37. http://people.uncw.edu/kubaskod/SEC_406_506/Classes/Class_6_Planning/Inquiry_Matrix.pdf

Gruenewald, D. A. (2003). The best of both worlds: a critical pedagogy of place. *Educational Researcher, 32*(4), 3–12. https://doi.org/10.3102/0013189X032004003

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology Journal*, *29*(2), 75–91. https://doi.org/10.1007/BF02766777

Guerrero, G. R., & Torres-Olave, B. (2022). Scientific literacy and agency within the Chilean science curriculum: A critical discourse analysis. *The Curriculum Journal*, *33*(3), 410–426. https://doi.org/10.1002/curj.141

Gurwitsch, A. (1964). *The Field of Consciousness*. Duquesne University Press.

Guskey, R. T. (2002). Professional development and teacher change. *Teachers and Teaching: Theory and Practice, 8*(3/4), 381–91. https://doi.org/10.1080/135406002100000512

Hadzigeorgiou, Y. (2015). A critique of science education as sociopolitical action from the perspective of liberal education. *Science & Education, 24*, 259–280. https://doi.org/10.1007/s11191-014-9728-4

Hajar, A. (2021). Theoretical foundations of phenomenography: a critical review. *Higher Education Research & Development*, *40*(7), 1421–1436. https://doi.org/10.1080/07294360.2020.1833844

Hallett, F. (2009). *The reality of study support: a phenomenographic and activity theory analysis* (Publication No. 133420) [Doctoral dissertation, Lancaster University]. https://eprints.lancs.ac.uk/id/eprint/133420/

Hanfstingl, B., Rauch, F., & Zehetmeier, S. (2019). Lesson study, learning study and action research: Are there more differences than a discussion about terms and schools?. *Educational Action Research*, *27*(4), 455–459. https://doi.org/10.1080/09650792.2019.1652450

Harding, T., & Fuchs, T. (2021). Not another climate change headline: The case of a Canadian teacher professional development program. *Education in Science*, *286*, 15–17. https://www.ase.org.uk/resources/education-in-science/issue-286/feature-climate-change-education

Hargreaves, A. (2019). Teacher collaboration: 30 years of research on its nature, forms, limitations and effects. *Teachers and Teaching: Theory and Practice*, *25*(5), 603–621. https://doi.org/10.1080/13540602.2019.1639499

Hargreaves, A., & Goodson, I. (2006). Educational change over time? The sustainability and non–sustainability of three decades of secondary school change and continuity. *Educational Administration Quarterly, 42*(1), 3–41. https://doi.org/10.1177/0013161X05277975

Han, S. W., Borgonovi, F., & Guerriero, S. (2018). What motivates high school students to want to be teachers? The role of salary, working conditions, and societal evaluations about occupations in a comparative perspective. *American Educational Research Journal, 55*(1), 3–39. https://doi.org/10.3102/0002831217729875

Han, F., & Ellis, R. A. (2019). Using phenomenography to tackle key challenges in science education. *Frontiers in Psychology*, *10,* 1–10. https://doi.org/10.3389/fpsyg.2019.01414

Harris, L. R. (2011). Phenomenographic perspectives on the structure of conceptions: The origins, purposes, strengths, and limitations of the what/how and referential/structural frameworks. *Educational Research Review, 6*(2), 109–124. https://doi.org/10.1016/j.edurev.2011.01.002

Hart, P., Jickling, B., & Kool, R. (1999). Starting points: Questions of quality in environmental education. *Canadian Journal of Environmental Education, 4,* Summer, 104–124. https://cjee.lakeheadu.ca/article/view/323/264

Herman, B. C., Newton, M. H., & Zeidler, D. L. (2021). Impact of place-based socioscientific issues instruction on students' contextualization of socioscientific orientations. *Science Education*, *105*(4), 585–627. https://doi.org/10.1002/sce.21618

Herman, B. C., Owens, D. C., Oertli, R. T., Zangori, L. A., & Newton, M. H. (2019). Exploring the complexity of students' scientific explanations and associated nature of science views within a place–based socioscientific issue context. *Science & Education*, *28*(3), 329–366. https://doi.org/10.1007/s11191-019-00034-4

Herman, B.C., Sadler, T. D., Zeidler, D. L., & Newton, M. H. (2018). A socioscientific issues approach to environmental education. In G. Reis, & J. Scott (Eds.), *International perspectives on the theory and practice of environmental education: A reader. Environmental discourses in science education* (Vol. 3, pp. 145–161). Springer. https://doi.org/10.1007/978-3-319-67732-3_11

Herreid, C. F., & Schiller, N. A. (2013). Case studies and the flipped classroom. *Journal of College Science Teaching*, *42*(5), 62–66. https://www.jstor.org/stable/43631584

Hervas, G. (2021). Lesson study as a faculty development initiative in higher education: A systematic review. *AERA open*, *7*(1), 1–19. https://doi.org/10.1177/2332858420982564

Hodson, D. (1999). Going beyond cultural pluralism: Science education for socio-political action. *Science Education, 83*(6), 775–796. https://doi.org/10.1002/(SICI)1098-237X(199911)83:6<775::AID-SCE8>3.0.CO;2-8

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*, 645–670. https://doi.org/10.1080/09500690305021

Hodson, D. (2010) Science education as a call to action. *Canadian Journal of Science, Mathematics and Technology Education*, *10*(3), 197–206. https://doi.org/10.1080/14926156.2010.504478

Hodson, D. (2011). *Looking to the future: Building a curriculum for social activism*. Sense Publishers. https://doi.org/10.1007/978-94-6091-472-0_3

Hodson, D. (2013). Don't be nervous, don't be flustered, don't be scared. Be prepared. *Canadian Journal of Science, Mathematics and Technology Education*, *13*(4), 313–331. https://doi.org/10.1080/14926156.2013.845327

Hodson, D. (2014). Becoming part of the solution: Learning about activism, learning through activism, learning from activism. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education* (pp. 67–98). Springer. https://doi.org/10.1007/978-94-007-4360-1_5

Hodson, D. (2020). Going beyond STS education: Building a curriculum for sociopolitical activism. *Canadian Journal of Science, Mathematics and Technology Education*, *20*(4), 592–622. https://doi.org/10.1007/s42330-020-00114-6

Hodson, D., & Wong, S. L. (2017). Going beyond the consensus view: Broadening and enriching the scope of NOS-oriented curricula. *Canadian Journal of Science, Mathematics and Technology Education*, *17*(1), 3–17. https://doi.org/10.1080/14926156.2016.1271919

Hoeg, D., Lemelin, N., & Bencze, J. L. (2015). Sociopolitical development of private school children mobilising for disadvantaged others. *Cultural Studies of Science Education*, *10*(4), 1155–1174. https://doi.org/10.1007/s11422-014-9611-2

Hoeg, D., Williamson, T., & Bencze, L. (2017). School science ruling relations and resistance to activism in early secondary school science. In L. Bencze (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 49–66). Springer. https://doi.org/10.1007/978-3-319-55505-8_3

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education: A pedagogical justification and the state of the art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education, 9*, 1459–1483. https://doi.org/10.1007/s10763-010-9273-9

Holden, M. (2022). Exploring online lesson study as a vehicle for teacher collaborative professional learning. *International Journal for Lesson & Learning Studies*, (ahead-of-print). https://doi.org/10.1108/IJLLS-01-2022-0012

Holmqvist, M., Gustavsson, L., & Wernberg, A. (2007). Generative learning: Learning beyond the learning situation. *Educational Action Research*, *15*(2), 181–208. https://doi.org/10.1080/09650790701314684

Holmqvist, M. O., & Olander, C. (2017). Analysing teachers' operations when teaching students: what constitutes scientific theories? *International Journal of Science Education*, *39*(7), 840–862. https://doi.org/10.1080/09500693.2017.1310407

Horlacher, R. (2016). *The educated subject and the German concept of Bildung – A comparative cultural history*. Routledge. https://doi.org/10.4324/9781315814667

Hrastinski, S. (2021). Digital tools to support teacher professional development in lesson studies: a systematic literature review. *International Journal for Lesson and Learning Studies, 10*(2) 138–149. https://doi.org/10.1108/IJLLS-09-2020-0062

Huang, R., Helgevold, N., & Lang, J. (2021). Digital technologies, online learning and lesson study. *International Journal for Lesson & Learning Studies*, *10*(2), 105–117. https://doi.org/10.1108/IJLLS-03-2021-0018

Huffling, L. D., Carlone, H. B., & Benavides, A. (2017). Re-inhabiting place in contemporary rural communities: Moving toward a critical pedagogy of place. *Cultural Studies of Science Education*, *12*(1), 33–43. https://doi.org/10.1007/s11422-016-9756-2

Hughes, P. J., & Panzo, D. (2015). Developing an Organizational Leadership Graduate Program: A" CHAT" about leadership education. *Journal of Leadership Education*, *14*(1), 193–203. https://doi.org/10.12806/V14/I1/I1

Independent Schools Association of British Columbia. (2023). *Leadership and Collaboration Groups*. https://www.isabc.ca/microsite/leadership-and-collaboration-groups/#tab-groups

Intergenerational Landed Learning Project [ILLP]. (2023). *School year program*. https://landedlearning.educ.ubc.ca/school-year-program/

Isoda, M., Araya, R., Eddy, C., Matney, G. T., Williams, J., Calfucura, P., Aquirre, C., Becerra, P., Gormaz, R., & Soto-Andrade, J. (2017). Teaching energy efficiency: a cross-border public class and lesson study in STEM. *Interaction Design and Architecture (s) Journal*. https://scholarworks.bgsu.edu/teach_learn_pub/33.

Jedrzejko, N., Margolick, J., Nguyen, J. H., Ding, M., Kisa, P., Ball-Banting, E., ... & Joos, E. (2021). A systematic review of global surgery partnerships and a proposed framework for sustainability. *Canadian Journal of Surgery*, *64*(3), 280–288. https://doi.org/10.1503/cjs.010719

Jedrzejko, N., Wong, A., MacNeill, A. J., & Hamilton, T. D. (2022). Predictors of Small Bowel Obstruction Post-Cytoreductive Surgery and Hyperthermic Intraperitoneal Chemotherapy. *Journal of Gastrointestinal Surgery*, 26(10), 2176–2183. https://doi.org/10.1007/s11605-022-05394-x

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development*, *47*(1), 61–79. https://doi.org/10.1007/BF02299477

Joubert, J., Callaghan, R. & Engelbrecht, J. (2020). Lesson study in a blended approach to support isolated teachers in teaching with technology. *ZDM Mathematics Education, 52*, 907–925. https://doi.org/10.1007/s11858-020-01161-x

Justi, R., & Van Driel, J. (2006). The use of the interconnected model of teacher professional growth for understanding the development of science teachers' knowledge on models and modelling. *Teaching and Teacher Education*, *22*(4), 437–450. https://doi.org/10.1016/j.tate.2005.11.011

Kahn, S., & 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), 261–281. https://doi.org/10.1007/s10972-016-9458-3

Kahlke, R., Lee, M., & Eva, K. (2023). Critical reviews in health professions education research. *Journal of Graduate Medical Education, 15*(2), 180–185. https://doi.org/10.4300/JGME-D-23-00154.1

Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching*, *53*(5), 667–682. https://doi.org/10.1002/tea.21305

Karisan, D., & Zeidler, D. L. (2017). Contextualization of nature of science within the socioscientific issues framework: A review of research. *International Journal of Education in Mathematics, Science and Technology*, *5*(2), 139–152. https://doi.org/10.18404/ijemst.270186

Kayumova, S., Avraamidou, L., & Adams, J. D. (2018). Science education: Diversity, equity and the big picture. In L. Bryan & K. Tobin (Eds.), *Critical Issues and Bold Visions for Science Education* (pp. 285–297). Brill Sense. https://doi.org/10.1163/9789004389663_016

Kennedy, M. M. (2016). How does professional development improve teaching? *Review of Educational Research, 86*(4), 945–980. https://doi.org/10.3102/0034654315626800

Kerstetter, K. (2012). Insider, outsider, or somewhere between: The impact of researchers' identities on the community-based research process. *Journal of Rural Social Sciences*, *27*(2), 7–19. https://egrove.olemiss.edu/jrss/vol27/iss2/7/

Khishfe, R. (2014). Explicit nature of science and argumentation instruction in the context of socioscientific issues: An effect on student learning and transfer. *International Journal of Science Education*, *36*(6), 974–1016. https://doi.org/10.1080/09500693.2013.832004

Khishfe, R., Alshaya, F. S., BouJaoude, S., Mansour, N., & Alrudiyan, K. I. (2017). Students' understandings of nature of science and their arguments in the context of four socio-scientific issues. *International Journal of Science Education*, *39*(3), 299–334. https://doi.org/10.1080/09500693.2017.1280741

Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching,43*(4), 395–418. https://doi.org/10.1002/tea.20137

Kincheloe, J. L., & Steinberg, S. R. (1998). Lesson plans from the outer limits: Unauthorized methods. In J. L. Kincheloe & S. R. Steinberg (Eds.), *Unauthorized methods: Strategies for critical teaching* (pp. 1-23). Routledge.

Kinslow, A. T., Sadler, T. D., & Nguyen, H. T. (2018). Socio-scientific reasoning and environmental literacy in a field-based ecology class. *Environmental Education Research*, 25(3), 388–410. https://doi.org/10.1080/13504622.2018.1442418

Kitsilano. (2017). *How to become an urban beekeeper in Vancouver*. Kitsilano. https://www.kitsilano.ca/2014/08/05/how-to-become-an-urban-beekeeper-in-vancouver/

Knaack, L. (2018). *BC K-12 New Curriculum: Roll Out Timeline*. Centre for Innovation and Excellence, Vancouver Island University. https://www.cotronline.ca/pluginfile.php/495272/mod_resource/content/1/BC%20K-12%20Curriculum%20Timeline%20of%20Rollout.pdf

Ko, P. Y. (2019a). Beyond labels: what are the salient features of lesson study and learning study?. *Educational Action Research*, *27*(4), 543–563. https://doi.org/10.1080/09650792.2018.1530126

Ko, P.Y. (2019b). Transcending conventional assessment boundaries in conducting learning study: a case in Hong Kong. *International Journal for Lesson and Learning Studies, 8*(3), 212–228. https://doi.org/10.1108/IJLLS-10-2018-0078

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

Koutsouris, G., Norwich, B., Fujita, T., Ralph, T., Adlam, A. and Milton, F. (2017). Piloting a dispersed and inter–professional lesson study using technology to link team members at a distance. *Technology, Pedagogy and Education, 26*(5), 587–599. https://doi.org/10.1080/1475939X.2017.1364290

Krstovic, M. (2017). Learning about youth engagement in research-informed and negotiated actions on socio-scientific issues. In L. Bencze (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 93–114). Springer. https://doi.org/10.1007/978-3-319-55505-8_6

Kudryavtsev, A., Krasny, M. E., & Stedman, R. C. (2012). The impact of environmental education on sense of place among urban youth. *Ecosphere, 3*(4), 1–15. https://doi.org/10.1890/ES11-00318.1

Kullberg, A. (2010). *What is Taught and What is Learned? Professional Insights Gained and Shared by Teachers of Mathematics* (Publication No. 293) [Doctoral dissertation, Acta Universitatis Gothoburgensis]. https://gupea.ub.gu.se/handle/2077/22180

Kullberg, A., Runesson, U., Marton, F., Vikström, A., Nilsson, P., Mårtensson, P., & Häggström, J. (2016). Teaching one thing at a time or several things together?–teachers changing their way of handling the object of learning by being engaged in a theory-based professional learning community in mathematics and science. *Teachers and Teaching*, *22*(6), 745–759. https://doi.org/10.1080/13540602.2016.1158957

Kullberg, A., Vikström, A., & Runesson, U. (2019). *Mechanisms enabling knowledge production in learning study.* International Journal for Lesson and Learning Studies, 9(1), 78–91. https://doi.org/10.1108/IJLLS-11-2018-0084

Kulviwat, S., Guo, C. & Engchanil, N. (2004). Determinants of online information search: a critical review and assessment. *Internet Research: Electronic Networking Applications and Policy, 14*(3), 245–53. https://doi.org/10.1108/10662240410542670

Kush, J. M., Badillo-Goicoechea, E., Musci, R. J., & Stuart, E. A. Teachers' Mental Health During the COVID-19 Pandemic. (2022). *Educational Researcher*, *51*(9), 593–597. https://doi.org/10.3102/0013189X221134281

Lai, K. C., Chan, K. W., Ko, K. W., & So, K. S. (2005). Teaching as a career: A perspective from Hong Kong senior secondary students. *Journal of Education for Teaching, 31*(3), 153–168. https://doi.org/10.1080/02607470500168974

Langemeyer, I., & Roth, W. M. (2006). Is cultural-historical activity theory threatened to fall short of its own principles and possibilities as a dialectical social science?. *Outlines. Critical Practice Studies*, *8*(2), 20–42. https://doi.org/10.7146/ocps.v8i2.2090

Lantz-Andersson, A., Lundin, M., & Selwyn, N. (2018). Twenty years of online teacher communities: A systematic review of formally-organized and informally-developed professional learning groups. *Teaching and Teacher Education*, *75*, 302–315. https://doi.org/10.1016/j.tate.2018.07.008

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory.* Oxford University Press.

Layton, D. (1972). Science as general education. *Trends in Education, 25*, 11–14.

Leader, M.S. (2021). Kelowna school embraces new container farm. *Country Life in BC, 107*(1). https://www.countrylifeinbc.com/kelowna-school-embraces-new-container-farm/

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Lawrence Erlbaum.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*, 497–521. https://doi.org/10.1002/tea.10034

Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education, 23*(2), 285–302. https://doi.org/10.1007/s11191-012-9503-3

Lee, H., & Witz, K. G. (2009). Science teachers' inspiration for teaching socio-scientific issues: Disconnection with reform efforts. *International Journal of Science Education*, *31*(7), 931–960. https://doi.org/10.1080/09500690801898903

Lee, H., & Yang, J. E. (2019). Science teachers taking their first steps toward teaching socioscientific issues through collaborative action research. *Research in Science Education, 49*(1), 51–71. https://doi.org/10.1007/s11165-017-9614-6

Lee, H., Yoo, J., Choi, K., Kim, S. W., Krajcik, J., Herman, B. C., & Zeidler, D. L. (2013). Socioscientific issues as a vehicle for promoting character and values for global citizens. *International Journal of Science Education*, *35*(12), 2079–2113. https://doi.org/10.1080/09500693.2012.749546

Lee, N. & Morimoto, K. (2021). Walking curricular paths in the virtual: The Stanley Parable and Minecraft. In A. Lasczik, A., R. L. Irwin, Cutter-Mackenzie-Knowles, D. Rousell, & N. Lee (Eds.), *Walking with A/r/tography* (pp. 39-48). Springer.

Lefstein, A., Vedder-Weiss, D., & Segal, A. (2020). Relocating research on teacher learning: Toward pedagogically productive talk. *Educational Researcher*, *49*(5), 360–368. https://doi.org/10.3102/0013189X20922998

Leonard, A. (2010). *The story of stuff: How our obsession with stuff is trashing the planet, our communities, and our health – And a vision for change.* Free Press.

Leonard, J., Chamberlin, S. A., Johnson, J. B., & Verma, G. (2016). Social justice, place, and equitable science education: Broadening urban students' opportunities to learn. *The Urban Review, 48*, 355–379. https://doi.org/10.1007/s11256-016-0358-9

Leontiev, A. A. (1981). Sign and activity. In J. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 241–255). Sharpe.

Leung, J. S. C., & Cheng, M. M. W. (2020). Conceptual change in socioscientific issues: Learning about obesity. *International Journal of Science Education*, *42*(18), 3134–3158. https://doi.org/10.1080/09500693.2020.1856966

Levinson, R. (2010). Science education and democratic participation: An uneasy congruence? *Studies in Science Education, 46*(1), 69–119. https://doi.org/10.1080/03057260903562433

Levinson, R. (2018a). *Real*ising the school science curriculum. *The Curriculum Journal*, *29*(4), 522–537. https://doi.org/10.1080/09585176.2018.1504314

Levinson, R. (2018b). Introducing socio-scientific inquiry-based learning (SSIBL). *School Science Review*, *100*(371), 31–35. https://www.ase.org.uk/system/files/SSR_December_2018_031-035_Levinson_0.pdf

Lewis, C. (2009). What is the nature of knowledge development in lesson study?. *Educational Action Research*, *17*(1), 95–110. https://doi.org/10.1080/09650790802667477

Lewis, C., Friedkin, S., Emerson, K., Henn, L., & Goldsmith, L. (2019). How does lesson study work? Toward a theory of lesson study process and impact. In R. Huang, A. Takahashi, J. A Ponte (Eds.), *Theory and practice of lesson study in mathematics: An international perspective* (pp. 14–34). Springer. https://doi.org/10.1007/978-3-030-04031-4_2

Lewis, C., Perry, R., & Hurd, J. (2004). A deeper look at lesson study. *Educational Leadership, 61*, 18–22. https://cursa.ihmc.us/rid=1Q19N0QF9-BHMDY-2TYD/DeeperLookatLS.pdf

Lewis, C., Perry, R. R., & Hurd, J. (2009). Improving mathematics instruction through lesson study: A theoretical model and North American case. *Journal of Mathematics Teacher Education, 12*, 285–304. https://doi.org/10.1007/s10857-009-9102-7

Lewis, C., & Tsuchida, I. (1998). A lesson is like a swiftly flowing river: Research lessons and the improvement of Japanese education. *American Educator*, *22*(Winter), 12–17 & 50–52. https://doi.org/10.1177/136548029900200117

Lo, M.L. (2009). The development of the learning study approach in classroom research in Hong Kong. *Educational Research Journal, 24*(1), 165–184. https://hkier.cuhk.edu.hk/en/journal_index.asp?pageid=7110

Lo, M. L. (2012). *Variation Theory and the Improvement of Teaching and Learning*. Acta Universitatis Gothoburgensis.

Lo, M. L. (2016). You can only see what you have chosen to see. *International Journal for Lesson and Learning Studies*, *5*(3), 170–179. https://doi.org/10.1108/IJLLS-05-2016-0011

Lo, M.L., Chik, P.M., & Pang, M. F. (2006). Patterns of variation in teaching the colour of light to primary 3 students. *Instructional Science, 34*(1), 1–19. https://doi.org/10.1007/s11251-005-3348-y

Lo, M.L., Hung, H.H.Y., & Chik, P.P.M. (2007). Improving teaching and learning through a learning study — Using patterns of variation to teach electro-chemical series in Hong Kong. *Curriculum Perspectives, 27*(3), 49–62. https://bibliography.lib.eduhk.hk/tc/bibs/3b7fa791

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

Lincoln, Y. S., & Guba, E. G. (2013). *The constructivist credo*. Left Coast Press.

Linder, C., & Fraser, D. (2009). Higher education science and engineering: Generating interaction with the variation perspective on learning. *Education as Change*, *13*(2), 277–291. https://doi.org/10.1080/16823200903234802

Liu, X. (2013). Expanding notions of scientific literacy: a reconceptualization of aims of science education in the knowledge society. In N. Mansour & R. Wegerif (Eds.), *Science education for diversity* (pp. 23–39). Springer. https://doi.org/10.1007/978-94-007-4563-6_2

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28*, 591–613. https://doi.org/10.1080/09500690500339621

Lundmark, C. (2003). The politics of recycling—a liberal democratic dilemma?. *European Environment*, *13*(2), 120–131. https://doi.org/10.1002/eet.315

Machi, E. (2009). *Improving U.S. competitiveness: With k-12 STEM education and training*. The Heritage Foundation. https://www.heritage.org/education/report/improving-us-competitiveness-k-12-stem-education-and-training

Mackenzie, A.H. (2020). Social justice in the science classroom. *The Science Teacher, 87*(7). https://www.nsta.org/science-teacher/science-teacher-march-2020

MacLeod, K. (2014). Pre-Service Teachers' Perceptions of Teaching STSE-Based High School Physics: Implications for Post-Secondary Studies. *European Journal of Physics Education, 5*(1), 1–15. https://doi.org/10.20308/ejpe.21926

Mansour, N. (2010). Impact of the Knowledge and Beliefs of Egyptian Science Teachers in Integrating a STS based Curriculum: A Sociocultural Perspective. *Journal of Science Teacher Education, 21*(5), 513–534. https://doi.org/10.1007/s10972-010-9193-0

Martin, L., & Towers, J. (2016). Folding back and growing mathematical understanding: a longitudinal study of learning. *International Journal for Lesson and Learning Studies*, *5*(4), 281–294. https://doi.org/10.1108/IJLLS-04-2016-0010

Martensson, P., & Hansson, H. (2018). Challenging teachers' ideas about what students need to learn: teachers' collaborative work in subject didactic groups. *International Journal for Lesson and Learning Studies, 7*(2), 98–110. https://doi.org/10.1108/IJLLS-11-2017-0048

Marton, F. (1981). Phenomenography—describing conceptions of the world around us. *Instructional Science*, *10*(2), 177–200. https://doi.org/10.1007/BF00132516

Marton, F. (1986). Phenomenography—a research approach to investigating different understandings of reality. *Journal of Thought*, 28–49. https://www.jstor.org/stable/42589189

Marton, F. (2006). Sameness and difference in transfer. *The Journal of the Learning Sciences*, *15*(4), 499–535. https://doi.org/10.1207/s15327809jls1504_3

Marton, F., & Booth, S. (1997). *Learning and awareness*. Lawrence Erlbaum Associates.

Marton, F., & Tsui, A. (2004). *Classroom discourse and the space of learning.* Lawrence Erlbaum. https://doi.org/10.4324/9781410609762

Mathison, S. (1988). Why triangulate? *Educational Researcher, 17*, 13–17. https://doi.org/10.3102/0013189X017002013

Maybee, C., Bruce, C. S., Lupton, M., & Pang, M. F. (2019). Informed learning design: Teaching and learning through engagement with information. *Higher Education Research & Development*, *38*(3), 579–593. https://doi.org/10.1080/07294360.2018.1545748

McCarthy, S., Hunter, J., & Keller, J. (2019, February 25). NEB says Trans Mountain pipeline expansion in public interest despite 'adverse' impact on whale population. *The Globe and Mail*. https://www.theglobeandmail.com/

McClaren, M. & Hammond, B. (2005). Integrating education and action in environmental education. In E.A. Johnson & M.J. Mappin (Eds.), *Environmental education and advocacy: Changing perspectives of ecology and education* (pp. 267–291). Cambridge University Press.

McComas, W. F., Clough, M. P., & Almazroa, H. (2000). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 3–39). Kluwer. https://doi.org/10.1007/0-306-47215-5_1

McElroy, J. (2020, March 16). City of Vancouver closes virtually all public spaces as part of COVID-19 prevention measures. *Canadian Broadcasting Corporation.* https://www.cbc.ca/news/canada/british-columbia/city-vancouver-covid-19-march-16-1.5499266

McKernan, J. (2008). *Curriculum and imagination: Process theory, pedagogy, and action research.* Routledge.

Meichtry, Y., & Smith, J. (2007). The impact of a place-based professional development program on teachers' confidence, attitudes, and classroom practices. *The Journal of Environmental Education*, *38*(2), 15–32. https://doi.org/10.3200/JOEE.38.1.15-34

Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., ... & Bevan, B. (2021). The trouble with STEAM and why we use it anyway. *Science Education*, *105*(2), 209-231. https://doi.org/10.1002/sce.21605

Merriam, S. B., Johnson-Bailey, J., Lee, M. Y., Kee, Y., Ntseane, G., & Muhamad, M. (2001). Power and positionality: Negotiating insider/outsider status within and across cultures. *International Journal of Lifelong Education*, *20*(5), 405–416. https://doi.org/10.1080/02601370120490

Miao, Y., Van der Klink, M., Boon, J., Sloep, P., & Koper, R. (2009). Enabling teachers to develop pedagogically sound and technically executable learning designs. *Distance Education*, *30*(2), 259-276. https://doi.org/10.1080/01587910903023223

Miechie, M., Tan, Y. S. M., & Adler, D. J. (2019). Towards a conceptual-based, student-centred pedagogy. *International Journal for Lesson and Learning Studies*, *8*(4), 334–347. https://doi.org/10.1108/IJLLS-04-2019-0038

Mishler, E. (1986). Meaning in context: Is there any other kind?. *Harvard Educational Review*, *49*(1), 1–19. https://doi.org/10.17763/haer.49.1.b748n4133677245p

Mitchell, R. (2013). What is professional development, how does it occur in individuals, and how may it be used by educational leaders and managers for the purpose of school improvement?. *Professional Development in Education*, *39*(3), 387–400. https://doi.org/10.1080/19415257.2012.762721

Mockler, N. (2013). Teacher professional learning in a neoliberal age: Audit, professionalism and identity. *Australian Journal of Teacher Education (Online)*, *38*(10), 35–47. https://doi.org/10.14221/ajte.2013v38n10.8

Molyneux, T. M., Zeni, M., & Oberle, E. (2022). Choose Your Own Adventure: Promoting Social and Emotional Development Through Outdoor Learning. *Early Childhood Education Journal*, 1-15. https://doi.org/10.1007/s10643-022-01394-3

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, *25*(6), 791–812. https://doi.org/10.1080/13504622.2017.1360842

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

Morris, A. K., & Hiebert, J. (2011). Creating shared instructional products: An alternative approach to improving teaching. *Educational Researcher, 40*(1), 5–14. https://doi.org/10.3102/0013189X10393501

Mortillaro, N. (2019, September 28). Climate lessons from the classroom spill into the streets. *CBC News.* https://www.cbc.ca/news/technology/global-climate-strike-kids-1.5300850

Mueller, M. P., & Zeidler, D. L. (2010). Moral-ethical character and science education: Ecojustice ethics through socioscientific issues (SSI). In D. Tippins, M. Mueller, M. van Eijck, and J. Adams (Eds) *Cultural studies and environmentalism: The confluence of ecojustice, place-based (science) education, and indigenous knowledge systems* (pp. 105–128). Springer. https://doi.org/10.1007/978-90-481-3929-3_8

National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards.* Board on Science Education, Division of Behavioral and Social Sciences and Education. National Academies Press. https://nap.nationalacademies.org/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

National Research Council (NRC). (1996). *National science education standards.* National Academies Press. https://nap.nationalacademies.org/catalog/4962/national-science-education-standards

Nelson, T. H., Deuel, A., Slavit, D., & Kennedy, A. (2010). Leading deep conversations in collaborative inquiry groups. *The Clearing House*, *83*(5), 175–179. https://doi.org/10.1080/00098650903505498

Nida, S., Marsuki, M. F., & Eilks, I. (2021). Palm-Oil-Based biodiesel in Indonesia: A case study on a socioscientific issue that engages students to learn chemistry and its impact on society. *Journal of Chemical Education*, *98*(8), 2536–2548. https://doi.org/10.1021/acs.jchemed.1c00244

Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education*, *36*(11), 1794–1814. https://doi.org/10.1080/09500693.2013.879621

Nilsson, P., & Vikström, A. (2015). Making PCK explicit—Capturing science teachers' pedagogical content knowledge (PCK) in the science classroom. *International Journal of Science Education*, *37*(17), 2836–2857. https://doi.org/10.1080/09500693.2015.1106614

Noddings, N. (2004). The False Promise of the Paideia: A Critical review of the Paideia Proposal. In D. J. Flinders & S. J. Thornton (Eds.), *The Curriculum Studies Reader* (2nd ed., pp. 163–171). RoutledgeFalmer.

Nuthall, G. (2004). Relating classroom teaching to students learning: A critical analysis of why research has failed to bridge the theory-practice gap. *Harward Educational Review, 74*, 273–306. https://doi.org/10.17763/haer.74.3.e08k1276713824u5

Obermeyer, Z., Powers, B., Vogeli, C., & Mullainathan, S. (2019). Dissecting racial bias in an algorithm used to manage the health of populations. *Science*, *366*(6464), 447–453. https://doi.org/10.1126/science.aax2342

Olteanu, L. (2017). Distributive law as object of learning through direct and inverse tasks. *International Journal for Lesson and Learning Studies, 6*(1), 56–65. https://doi.org/10.1108/IJLLS-05-2016-0014

Ontario Ministry of Education [OME]. (2008). *The Ontario curriculum, grades 9 and 10: Science*. Toronto, ON: Queen's Printer for Ontario. https://www.edu.gov.on.ca/eng/curriculum/secondary/science910_2008.pdf

Onwu, G. (2017). Towards a Socially Responsible Science Education. In B. Akpan (Ed.) *Science Education: A Global Perspective* (pp. 235–251). Springer, Cham. https://doi.org/10.1007/978-3-319-32351-0_12

Olander, C., & Olander, M. H. (2013). Professional development through the use of learning study: Contributions to pedagogical content knowledge in biology. *Procedia-Social and Behavioral Sciences*, *89*, 205–212. https://doi.org/10.1016/j.sbspro.2013.08.835

Olander, M.H. and Sandberg, B. (2013), Teaching democracy – a complex object of learning, *International Journal for Lesson and Learning Studies, 2*(3), 281–299. https://doi.org/10.1108/IJLLS-01-2013-0005

Ord, T. (2020). *The precipice: Existential risk and the future of humanity*. Hachette Books.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307–332. https://doi.org/10.3102/00346543062003307

Pacific Salmon Foundation. (2023). *Community Investment*. PSF. https://psf.ca/work/community/

Pang, M. F. (2003). Two faces of variation: On continuity in the phenomenographic movement. *Scandinavian Journal of Educational Research*, *47*(2), 145–156. https://doi.org/10.1080/00313830308612

Pang, M. F. (2006). The use of learning study to enhance teacher professional learning in Hong Kong. *Teaching Education*, *17*(1), 27–42. https://doi.org/10.1080/10476210500527915

Pang, M. F. (2010). Boosting financial literacy: Benefits from learning study. Instructional Science, 38(6), 659–677. https://doi.org/10.1007/s11251-009-9094-9

Pang, M. F. (2019). Enhancing the generative learning of young people in the domain of financial literacy through learning study. *International Journal for Lesson and Learning Studies, 8*(3), 170–182. https://doi.org/10.1108/IJLLS-09-2018-0065

Pang, M. F., Linder, C. & Fraser, D. (2006). Beyond lesson studies and design experiments – Using theoretical tools in practice and finding out how they work. *International Review of Economics Education, 5*(1), 28–45. https://doi.org/10.1007/s11251-011-9191-4

Pang, M. F., & Lo, M. L. (2012). Learning study: Helping teachers to use theory, develop professionally, and produce new knowledge to be shared. *Instructional Science*, *40*(3), 589–606. https://doi.org/10.1007/s11251-011-9191-4

Pang, M. F., & Marton, F. (2003). Beyond "lesson study": Comparing two ways of facilitating the grasp of some economic concepts. *Instructional Science, 31*, 175–194. https://doi.org/10.1023/A:1023280619632

Pang, M. F., & Marton, F. (2005). Learning theory as teaching resource: Enhancing students' understanding of economic concepts. *Instructional Science, 33*(2), 159–191. https://doi.org/10.1007/s11251-005-2811-0

Pang, M.F., & Runesson, U. (2019). The learning study: recent trends and developments. *International Journal for Lesson and Learning Studies, 8*(3), 162–169. https://doi.org/10.1108/IJLLS-07-2019-093

Parker, C., Scott, S., & Geddes, A., (2019). Snowball Sampling, In P. Atkinson, S. Delamont, A. Cernat, J.W. Sakshaug, & R.A. Williams (Eds.), *SAGE Online Research Methods Foundations.* https://doi.org/10.4135/9781526421036831710

Pascale, R., Sternin, J., & Sternin, M. (2010) *The power of positive deviance: How unlikely innovators solve the world's toughest problems.* Harvard University Press.

Pedretti, E. (1996). Facilitating action research in science, technology and society (STS) education: An experience in reflective practice. *Educational Action Research, 4*(3), 307–327. https://doi.org/10.1080/0965079960040303

Pedretti, E. (1997). Septic tank crisis: A case study of action research in science, technology and society education in an elementary school. *International Journal of Science Education, 19*(10), 1211 – 1230. https://doi.org/10.1080/0950069970191007

Pedretti, E., & Bellomo, K. (2013). A time for change: Advocating for STSE education through professional learning communities. *Canadian Journal of Science, Mathematics and Technology Education, 13*(4), 415–437. https://doi.org/10.1080/14926156.2012.679996

Pedretti, E. G., Bencze, L., Hewitt, J., Romkey, L., & Jivraj, A. (2008). Promoting issues-based STSE perspectives in science teacher education: Problems of identity and ideology. *Science & Education*, *17*(8-9), 941–960. https://doi.org/10.1007/s11191-006-9060-8

Pedretti, E., & Iannini, A. M. N. (2020). Towards fourth-generation science museums: Changing goals, changing roles. *Canadian Journal of Science, Mathematics and Technology Education*, *20*, 700–714. https://doi.org/10.1007/s42330-020-00128-0

Pedretti, E., & Nazir, J. (2011). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education, 95*(4), 601–626. https://doi.org/10.1002/sce.20435

Pedretti, E. & Nazir, J. (2015). Science, Technology and Society (STS). In R. Gunstone (Eds.) *Encyclopedia of Science Education* (pp. 932–935). Springer. https://doi.org/10.1007/978-94-007-2150-0_177

Phillips-MacNeil, C., Krstovic, M., & Bencze, L. (2017). Students socio-scientific actions: Using and gaining 'street smarts'. In L. Bencze (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 295–314). Springer. https://doi.org/10.1007/978-3-319-55505-8_13

Pierce, C. (2013). *Education in the age of biocapitalism: Optimizing educational life for a flat world.* Palgrave Macmillan.

Pinar, W. F. & Irwin, R. L. (Eds.) (2005). *Curriculum in a new key: The collected works of Ted T. Aoki*. Lawrence Erlbaum.

Potvin, P. (2017). The coexistence claim and its possible implications for success in teaching for conceptual "change." *European Journal of Science and Mathematics Education, 5*, 55–66. https://doi.org/10.30935/scimath/9497

Potvin, P., Masson, S., Lafortune, S. & Cyr, G. (2015). Persistence of the intuitive conception that heavier objects sink more: a reaction time study with different levels of interference. *International Journal of Science and Mathematics Education, 13*, 21–43. https://doi.org/10.1007/s10763-014-9520-6

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

Ramjewan, N. T., Zoras, B., & Bencze, L. (2017). Tensions on promoting social justice through STEPWISE pedagogies in an International Baccalaureate preparatory class. In L. Bencze (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 315–338). Springer. https://doi.org/10.1007/978-3-319-55505-8_14

Rasa, T., Palmgren, E., & Laherto, A. (2022). Futurising science education: Students' experiences from a course on futures thinking and quantum computing. *Instructional Science*, *50*(3), 425–447. https://doi.org/10.1007/s11251-021-09572-3

Richardson, J. T. (1999). The concepts and methods of phenomenographic research. *Review of educational research*, *69*(1), 53–82. https://doi.org/10.3102/00346543069001053

Rip, A. (1978). The social context of science, technology, and society courses in the universities. In E. Boeker & M. Gibbons (Eds.), *Science, society and education* (pp. 135–152). Vrie Universiteit.

Ripple, W., Wolf, C., Newsome, T., Barnard, P., Moomaw, W., & Grandcolas, P. (2019). World scientists' warning of a climate emergency. *BioScience*, *70*(1), 8–12. https://doi.org/10.1093/biosci/biz088

Ritchhart, R., & Church, M. (2020). *The power of making thinking visible: Practices to engage and empower all learners*. John Wiley & Sons.

Roberts, D.A. (2007). Scientific literacy / science literacy. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Lawrence Erlbaum Associates.

Roberts, D. (2011). Competing visions of scientific literacy: the influence of a science curriculum policy image. In C. Linder, L. Östmaan, L., D. Roberts, P. O. Wickman, G. Erickson, and A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 21–37). Routledge.

Romine, W. L., Sadler, T. D., Dauer, J. M., & Kinslow, A. (2020). Measurement of socio-scientific reasoning (SSR) and exploration of SSR as a progression of competencies. *International Journal of Science Education*, *42*(18), 2981–3002. https://doi.org/10.1080/09500693.2020.1849853

Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2017). Assessment of scientific literacy: Development and validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR). *Journal of Research in Science Teaching*, *54*(2), 274–295. https://doi.org/10.1002/tea.21368

Roseler, K., & Dentzau, M. W. (2013). Teacher professional development: A different perspective. *Cultural Studies of Science Education*, *8*(3), 619–622. https://doi.org/10.1007/s11422-013-9493-8

Roth, W. M. (2010). Activism: A category for theorizing learning. *Canadian Journal of Science, Mathematics and Technology Education*, *10*(3), 278–291. https://doi.org/10.1080/14926156.2010.504493

Roth, W.M., & Calabrese Barton, A. (2004). *Rethinking scientific literacy*. Routledge. https://doi.org/10.4324/9780203463918

Roth, M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education, 88*(2), 263–291. https://doi.org/10.1002/sce.10113

Roth, W. M., Lee, Y. J., & Hsu, P. L. (2009). A tool for changing the world: possibilities of cultural-historical activity theory to reinvigorate science education. *Studies in Science Education*, *45*(2), 131–167. https://doi.org/10.1080/03057260903142269

Rovio-Johansson, A., & Ingerman, Å. (2016). Continuity and development in the phenomenography and variation theory tradition. *Scandinavian Journal of Educational Research,* 60, 257–271. https://doi.org/10.1080/00313831.2016.1148074

Royce, C. (2010). A revolutionary model of professional development. *Science Scope, 34*(3), 6–9. https://www.jstor.org/stable/i40124484

Royea, D. A., & Nicol, C. (2019). Pre-service teachers' experiences of learning study: learning with and using variation theory. *Educational Action Research*, *27*(4), 564–580. https://doi.org/10.1080/09650792.2018.1515094

Runesson, U. (2015). Pedagogical and learning theories and the improvement and development of learning and lesson studies. *International Journal of Lesson and Learning Studies, 4*(3), 186–193. https://doi.org/10.1108/IJLLS-04-2015-0016

Runesson, U. (2016). Pedagogical and learning theories in lesson and learning studies–revisited. *International Journal for Lesson and Learning Studies*, *5*(4), 295–299. https://doi.org/10.1108/IJLLS-07-2016-0017

Runesson, U. & Gustafsson, L. (2010). *Learning study – knowledge production for teachers?* Paper presented at The World Association of Lesson Studies International Conference, Brunei Darussalam, December 9–10.

Ruitenberg, C. W. (2009). Educating political adversaries: Chantal Mouffe and radical democratic citizenship education. *Studies in Philosophy and Education, 28*, 269–281. https://doi.org/10.1007/s11217-008-9122-2

Sadler, T. D. (2009). Situated learning in science education: Socio–scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1–42. https://doi.org/10.1080/03057260802681839

Sadler, T. (Ed.). (2011). *Socio-scientific issues in the classroom: Teaching, learning and trends*. Springer. https://doi.org/10.1007/978-94-007-1159-4

Sadler, T.D., Amirshokoohi, A., Kazempour, M., & Allspaw, K.M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching, 43*(4), 353–376. https://doi.org/10.1002/tea.20142

Sadler, T. D., Barab, S., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371–391. https://doi.org/10.1007/s11165-006-9030-9

Sadler, P. M., Sonnert, G., Tai, R. H., & Klopfenstein, K. (2010). *AP: A Critical Examination of the Advanced Placement Program*. Harvard Education Press.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*, 909–921. https://doi.org/10.1002/tea.20327

Sadler, T. D., Foulk, J. A., & Friedrichsen, P. J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *International Journal of Education in Mathematics, Science and Technology*, *5*(2), 75–87. https://doi.org/10.18404/ijemst.55999

Sahlberg, P. (2011). *Finnish lessons: What can the world learn from educational change in Finland?* Teachers College Press.

Salas, R. N. (2021). Environmental racism and climate change—missed diagnoses. *New England Journal of Medicine*, *385*(11), 967–969. https://doi.org/10.1056/NEJMp2109160

Salinas, I., Guerrero, G., Satlov, M., & Hidalgo, P. (2022). Climate Change in Chile's School Science Curriculum. *Sustainability*, *14*(22), 15212. https://doi.org/10.3390/su142215212

Säljö, R. (1975). *Qualitative differences in learning as a function of the learner's conception of the task*. Acta Universitatis Gothoburgensis.

Säljö, R. (1988). Learning in educational settings: Methods of inquiry. In P. Ramsden (Ed.), *Improving learning. New perspectives* (pp. 32–48). Kogan Page

Säljö, R. (1994). Minding action. Conceiving of the world versus participating in cultural practices. *Nordisk Pedagogik, 14*, 71–80.

Säljö, R. (1997). Talk as data and practice - A critical look at phenomenographic inquiry and the appeal to experience. *Higher Education Research & Development, 16*(2), 173–190. https://doi.org/10.1080/0729436970160205

Sancar, R., Atal, D., & Deryakulu, D. (2021). A new framework for teachers' professional development. *Teaching and Teacher Education*, *101*, 103305. https://doi.org/10.1016/j.tate.2021.103305

Saito, E. (2012). Key issues of lesson study in Japan and the United States: A literature review. *Professional Development in Education*, *38*(5), 777–789. https://doi.org/10.1080/19415257.2012.668857

Sandberg, J. (1997). Are phenomenographic results reliable? *Higher Education Research and Development, 16*(2), 203–212. https://doi.org/10.1080/0729436970160207

Sandberg, J. (2005). How do we justify knowledge produced within interpretive approaches?. *Organizational research methods*, *8*(1), 41–68. https://doi.org/10.1177/1094428104272000

Sato, M., 2006. *Gakko no chosen* [Challenge by schools]. Shogakkan.

Schaffer, K., & El Halwany, S. (2020). Feeling Environmental Policing: Possibilities and Challenges for Socio-Ecological Justice. *Journal of the Canadian Association for Curriculum Studies*, *18*(1), 171–172. https://jcacs.journals.yorku.ca/index.php/jcacs/article/view/40539

Schindel Dimick, A. (2016). Exploring the potential and complexity of a critical pedagogy of place in urban science education. *Science Education, 100*(5), 814–836. https://doi.org/10.1002/sce.21233

Schneider, R. M. (2019). Illustrating and Developing Science Teachers' Pedagogical Content Knowledge Through Learning Study. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 167–186). Springer Singapore. https://doi.org/10.1007/978-981-13-5898-2_7

Schwandt, T. A. (2014). *The Sage dictionary of qualitative inquiry*. Sage publications. https://doi.org/10.4135/9781483398969

Seidel, S. (2010). Reflective inquiry in the round. In N. Lyons (Ed.) *Handbook of reflection and reflective inquiry: Mapping a way of knowing for professional reflective inquiry* (pp. 299-313), Springer. https://doi.org/10.1007/978-0-387-85744-2_15

Shen, B. S. P. (1975). Scientific literacy and the public understanding of science. In S. B. Day (Ed.), *The communication of scientific information* (pp. 44–52). Karger. https://doi.org/10.1159/000398072

Shulman, L. (2005) Signature pedagogies in the professions. *Daedalus: Journal of the American Academy of Arts and Sciences, 134*(3), 52–9. https://doi.org/10.1162/0011526054622015

Shtulman, A. & Valcarcel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition, 124*, 209–215. https://doi.org/10.1016/j.cognition.2012.04.005

Simonneaux, J., & Legardez, A. (2010). The epistemological and didactical challenges involved in teaching socially acute questions. The example of globalization. *Journal of Social Science Education, 9*, 24–35. https://www.jsse.org/index.php/jsse/article/view/539/536

Sinnes, A, T., Kyle, W. C. Jr., Alant, B., Kazima, M., Nampota, D., & Onwu, G. O. M. (Eds.). (2011). Editorial. *African Journal of Research in Mathematics, Science and Technology Education, 15(3*), 1–4. https://doi.org/10.1080/10288457.2011.10740714

Sjöström, J., & Eilks, I. (2018). Reconsidering different visions of scientific literacy and science education based on the concept of Bildung. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, metacognition, and culture in STEM education: Learning, teaching and assessment* (pp. 65–88). Springer International Publishing. https://doi.org/10.1007/978-3-319-66659-4_4

Sjöström, J., Eilks, I., & Zuin, V. G. (2016). Towards eco-reflexive science education. *Science & Education, 25*(3), 321–341. https://doi.org/10.1007/s11191-016-9818-6

Sjöström, J., Frerichs, N., Zuin, V. G., & Eilks, I. (2017). Use of the concept of Bildung in the international science education literature, its potential, and implications for teaching and learning. *Studies in Science Education, 53*(2), 165–192. https://doi.org/10.1080/03057267.2017.1384649

Skloot, R. (2017). *The immortal life of Henrietta Lacks*. Broadway Paperbacks.

Skultety, L., Gonzalez, G. and Vargas, G. (2017). Using technology to support teachers' lesson adaptations during lesson study. *Journal of Technology and Teacher Education, 25*(2), 185–213. https://www.learntechlib.org/primary/p/172139/

Smith, G.A. (2002). Place-based education: Learning to be where we are. *Phi Delta Kappan, 83*(8), 584–594. https://doi.org/10.1177/003172170208300806

Smith, V., Mack, F., & Akyea, S. (2004). African- American male honor students' views of teaching as a career choice. *Teacher Education Quarterly, 31*(2), 75–88.

Smith, G. A., & Sobel, D. (2014). *Place-and community-based education in schools*. New York: Routledge

Sobel, D. (2004). *Place-based education: Connecting classrooms and communities.* Orion Press.

Solomon, J., & Aikenhead, G. (1994). *STS education: International perspectives on reform. Ways of knowing science series*. Teachers College Press.

Somekh, B., & Zeichner, K. (2009). Action research for educational reform: Remodeling action research theories and practices in local contexts. *Educational Action Research,17*(1), 5–21. https://doi.org/10.1080/09650790802667402

Steele, A. (2013). Shifting currents: Science technology society and environment in Northern Ontario schools. *Brock Education Journal*, *23*(1), 18–42. https://doi.org/10.26522/brocked.v23i1.351

Steele, A. (2014). The seventh current: A case for the environment in STSE education. *Canadian Journal of Science, Mathematics and Technology Education, 14*(3), 238–251. https://doi.org/10.1080/14926156.2014.935527

Steele, A. (2016). Troubling STEM: Making a case for an ethics/STEM partnership. *Journal of Science Teacher Education*, *27*(4), 357–371. https://doi.org/10.1007/s10972-016-9463-6

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., Summerhayes, C. P., Barnosky, A. D., Cornell, S.E., Crucifix, M., Donges, J. F., Fetzer, I., Lade, S. J., Scheffer, M., Winkelmann, R., & Schellnhuber, H. J. (2018). Trajectories of the Earth system in the anthropocene. *Proceedings of the National Academy of Sciences of the United States of America, 115*(33), 8252–8259. https://doi.org/10.1073/pnas.1810141115

Stenhouse, L. (1975). *An Introduction to Curriculum Research and Development*. Heinemann

Stigler, J. W., & Hiebert, J. (1999). *The teaching gap.* The Free Press.

Stokes, L. R., Suh, J. M., & Curby, T. W. (2020). Examining the nature of teacher support during different iterations and modalities of lesson study implementation. *Professional Development in Education*, *46*(1), 97–111. https://doi.org/10.1080/19415257.2019.1634623

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques.* Sage.

Sue-Chue-Lam, C., Lalande, A., & MacNeill, A. (2022). From Low-Hanging Fruit to Deep Decarbonization—Sustainable Health Systems Beyond the Operating Room. *JAMA surgery*. https://doi.org/10.1001/jamasurg.2022.3896

Suh, J., Gallagher, M.A., Capen, L. & Birkhead, S. (2021). Enhancing teachers' noticing around mathematics teaching practices through video-based lesson study with peer coaching. *International Journal for Lesson and Learning Studies, 10*(2), 150–166. https://doi.org/10.1108/IJLLS-09-2020-0073

Sustainabiliteens. (2023). *About*. https://www.sustainabiliteens.org/

Svensson, L. (1976). *Study skill and learning*. Acta Universitatis Gothoburgensis.

Svensson, L. (1997). Theoretical foundations of phenomenography. *Higher Education Research & Development, 16*(2), 159–171. https://doi.org/10.1080/0729436970160204

Tan, Y.S.M. (2014a). Enriching a collaborative teacher inquiry discourse: exploring teachers' experiences of a theory-framed discourse in a Singapore case of lesson study. *Educational Action Research, 22*(3), 411–427. https://doi.org/10.1080/09650792.2014.880360

Tan, Y. S. M. (2014b). A researcher-facilitator's reflection: Implementing a Singapore case of learning study. *Teaching and Teacher Education*, *37*, 44–54. https://doi.org/10.1016/j.tate.2013.09.003

Tan, Y. S. M. (2017). Advancing teacher knowledge: Considerations for a learning study approach. In K. Tan, M. A. Heng, C. Lim-Ratnam (Eds.), *Curriculum Leadership by Middle Leaders* (pp. 224–240). Routledge. https://doi.org/10.4324/9781315760889-19

Tan, Y.S.M. (2018). Learning study is 'hard': case of pre-service biology teachers in British Columbia. *International Journal for Lesson and Learning Studies, 7*(1), 37–49. https://doi.org/10.1108/IJLLS-02-2017-0013

Tan, Y. S. M., & Amiel, J. J. (2022). Teachers learning to apply neuroscience to classroom instruction: case of professional development in British Columbia. *Professional Development in Education*, *48*(1), 70–87. https://doi.org/10.1080/19415257.2019.1689522

Tan, Y. S. M., Amiel, J. J., & Cheng, C. (2019a). Theorizing variation theory—a case of collaborative action research involving science teacher candidates. *Educational Action Research*, *28*(3), 443–461. https://doi.org/10.1080/09650792.2019.1575257

Tan, Y. S. M., Amiel, J. J., & Yaro, K. (2019b). Developing theoretical coherence in teaching and learning: case of neuroscience-framed learning study. *International Journal for Lesson and Learning Studies*, *8*(3), 229–243. https://doi.org/10.1108/IJLLS-10-2018-0072

Tan, Y. S. M., & Caleon, I. S. (2016). Problem finding in professional learning communities: A learning study approach. *Scandinavian Journal of Educational Research*, *60*(2), 127–146. https://doi.org/10.1080/00313831.2014.996596

Tan, Y. S. M., & Caleon, I. S. (2022). "It's not just about grades": Teachers' alternative perceptions of students performing at a low level and of these students' academic success. *Teaching and Teacher Education*, *118*, 103816. https://doi.org/10.1016/j.tate.2022.103816

Tan, Y. S. M., & Nashon, S. M. (2013). Promoting teacher learning through learning study discourse: The case of science teachers in Singapore. *Journal of Science Teacher Education*, *24*(5), 859–877. https://doi.org/10.1007/s10972-013-9340-5

Tan, Y. S. M., & Nashon, S. M. (2015). Promoting teachers' collaborative exploration of a new science curriculum: The case of a Singapore learning study. *Professional Development in Education*, *41*(4), 671–689. https://doi.org/10.1080/19415257.2014.944670

Taylor, D. L., & Booth, S. (2015). Secondary physical science teachers' conceptions of science teaching in a context of change. *International Journal of Science Education*, *37*(8), 1299–1320. https://doi.org/10.1080/09500693.2015.1035356

The Lesson Study Group. (2022). *Content Resources*. https://lessonresearch.net/resources/content-resources/

Thorsten, A. (2015). How teachers' practice knowledge is used and challenged in a learning study using variation theory as a tool. *International Journal for Lesson and Learning Studies, 4*(3), 274–287. https://doi.org/10.1108/IJLLS-08-2014-0030

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: From the perspective of teachers. *International Journal of Science Education, 39*(1), 44–61. https://doi.org/10.1080/09500693.2016.1264644

Tippet, C. & Milford, T. (Eds.) (2019). *Science education in Canada: consistencies, commonalities, and distinctions.* Springer International. https://doi.org/10.1007/978-3-030-06191-3

Truth and Reconciliation Commission of Canada (TRC). (2015). *Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada*. http://www.chaireconditionautochtone.fss.ulaval.ca/documents/pdf/Honouring-the-truth-reconciling-for-the-future.pdf

To, K. K., & Pang, M. F. (2019). A study of variation theory to enhance students' genre awareness and learning of genre features. *International Journal for Lesson and Learning Studies, 8*(3), 183 –194. https://doi.org/10.1108/IJLLS-10-2018-0070

Töytäri, A., Piirainen, A., Tynjälä, P., Vanhanen-Nuutinen, L., Mäki, K., & Ilves, V. (2016). Higher education teachers' descriptions of their own learning: a large-scale study of Finnish Universities of Applied Sciences. *Higher Education Research & Development*, *35*(6), 1284–1297. https://doi.org/10.1080/07294360.2016.1152574

Töytäri, A., Tynjälä, P., Piirainen, A., & Ilves, V. (2017). Higher education teachers' descriptions of their own learning: a quantitative perspective. *Higher Education Research & Development*, *36*(6), 1295–1304. https://doi.org/10.1080/07294360.2017.1303455

Tight, M. (2016). Phenomenography: The development and application of an innovative research design in higher education research. *International Journal of Social Research Methodology, 19*, 319–338. https://doi.org/10.1080/13645579.2015.1010284

Trigwell, K. (1994). The first stage of a phenomenographic study of phenomenography. In J. A. Bowden & E. Walsh (Eds.), *Phenomenographic research: Variations in method*. The Warburton symposium (pp. 56–72). Royal Melbourne Institute of Technology.

Tsang, V. W., Yu, A., Haines, M. J., Sagorin, Z., Mitchell, D., Ching, G., ... & Kestler, M. (2021). Transforming disruption into innovation: A partnership between the COVID–19 Medical Student Response Team and the University of British Columbia. *Academic Medicine*, *96*(12), 1650–1654. https://doi.org/10.1097/ACM.0000000000004156

Valladares, L. (2021). Scientific literacy and social transformation: Critical perspectives about science participation and emancipation. *Science & Education*, *30*(3), 557–587. https://doi.org/10.1007/s11191-021-00205-2

Van Rooij, E. C. M., Fokkens-Bruinsma, M., & Goedhart, M. J. (2020). Identifying potential secondary school teachers among science university students: A latent profile analysis. *Journal of Science Teacher Education, 31*(5), 556–577. https://doi.org/10.1080/1046560X.2020.1729478

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

Vesilind, E. M., & Jones, M. G. (1998). Gardens or graveyards: Science education reform and school culture. *Journal of Research in Science Teaching*, *35*(7), 757–775. https://doi.org/10.1002/(SICI)1098-2736(199809)35:7<757::AID-TEA6>3.0.CO;2-K

Vikström, A. (2014). What makes the difference? Teachers explore what must be taught and what must be learned in order to understand the particulate character of matter. *Journal of Science Teacher Education*, *25*(6), 709–727. https://doi.org/10.1007/s10972-014-9397-9

Vikström, A., Billström, A., Fazeli, P., Holm, M., Jonsson, K., Karlsson, G. & Rydström, P. (2013). Teachers' solutions: a learning study about solution chemistry in grade 8. *International Journal for Lesson and Learning Studies, 2*(1), 26–40. https://doi.org/10.1108/20468251311290114

Waldron, I. R. (2021). *There's something in the water: Environmental racism in Indigenous & Black communities*. Fernwood Publishing.

Walsh, E., Dall'Alba, G., Bowden, J., Martin, E., Marton, F., Masters, G., ... & Stephanou, A. (1993). Physics students' understanding of relative speed: A phenomenographic study. *Journal of Research in Science Teaching*, *30*(9), 1133–1148. https://doi.org/10.1002/tea.3660300910

Weaver, J. C., Matney, G., Goedde, A. M., Nadler, J. R., & Patterson, N. (2021). Digital tools to promote remote lesson study. *International Journal for Lesson & Learning Studies*, *10*(2), 187-201. https://doi.org/10.1108/IJLLS-09-2020-0072

Wei, G. (2019). How could cultural-historical activity theory inspire lesson study? In R. Huang, A. Takahashi, J. A Ponte (Eds.), *Theory and practice of lesson study in mathematics: An international perspective* (pp. 39–58). Springer Nature. https://doi.org/10.1007/978-3-030-04031-4_3

Weinstein, M., Blades, D., & Gleason, S. (2016). Questioning power: Deframing the STEM discourse. *Canadian Journal of Science, Mathematics and Technology Education, 16*(2), 201–212. https://doi.org/10.1080/14926156.2016.1166294

Werner, H. (1948). *Comparative Psychology of Mental Development*. International Universities Press.

Widjaja, W., Groves, S., & Ersozlu, Z. (2021). Designing and delivering an online lesson study unit in mathematics to pre-service primary teachers: opportunities and challenges. *International Journal for Lesson & Learning Studies*, *10(2)*, 230–242. https://doi.org/10.1108/IJLLS-10-2020-0080

Wong, E. D. (1995). Challenges confronting the researcher/teacher: Conflicts of purpose and conduct. *Educational researcher*, *24*(3), 22–28. https://doi.org/10.3102/0013189X024003022

Wong, S. L., Wan, Z., & Cheng, M. W. (2011). Learning nature of science through socio-scientific issues. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom*. Springer. https://doi.org/10.1007/978-94-007-1159-4_14

Wood, K. (2000). The experience of learning to teach: Changing student teachers' ways of understanding teaching. *Journal of Curriculum Studies, 32*(1), 75–93. https://doi.org/10.1080/002202700182862

Wood, K. (2013). A design for teacher education based on a systematic framework of variation to link teaching with learners' ways of experiencing the object of learning. *International Journal for Lesson and Learning Studies, 2*(1), 56–71. https://doi.org/10.1108/20468251311290132

Wood, K. (2017). Is There Really Any Difference between Lesson and Learning Study? Both Focus on Neriage. *International Journal for Lesson and Learning Studies, 6*(2), 118–123. https://doi.org/10.1108/IJLLS-02-2017-0008

Wood, K., Lu, C. and Andrew, V. (2015). Learning study, economics and cognitive bias: what is the object of learning? *International Journal for Lesson and Learning Studies, 4*(3), 288–301. https://doi.org/10.1108/IJLLS-12-2014-0048

Wood, K., & Sithamparam, S. (Eds.). (2015). *Realising Learning*. Routledge, London. https://doi.org/10.4324/9781315814216

Wood, M. L. (1991). Naming the illness: the power of words. *Family Medicine*, *23*(7), 534–538. https://pubmed.ncbi.nlm.nih.gov/1936736/

Yin, R. (2014). *Case study research* (5th ed.). Sage.

Yoshida, M. (1999). *Lesson study: A case study of a Japanese approach to improving instruction through school-based teacher development* (Publication No. 9951855) [Doctoral dissertation, University of Chicago]. ProQuest Dissertation Publishing.

Yu, S. V. (2019). *From conceptions to capacity: Conceptualizing the development of doctors' sense of professional practice and the implications for medical education* [Doctoral dissertation, Australian National University]. https://openresearch-repository.anu.edu.au/bitstream/1885/185087/6/2019%20Suet%20Voon%20Yu%20Thesis.pdf

Yurkofsky, M. M., Blum-Smith, S., & Brennan, K. (2019). Expanding outcomes: Exploring varied conceptions of teacher learning in an online professional development experience. *Teaching and Teacher Education*, *82*, 1–13. https://doi.org/10.1016/j.tate.2019.03.002

Zeidler, D. L. (2007). An inclusive view of scientific literacy: Core issues and future directions. In C. Linder, L. Ostman, & P. Wickman (Eds.), *Proceedings of the Linnaeus tercentenary symposium on Promoting Scientific Literacy: Science Education Research in Transaction* (pp. 72–85). Uppsala University.

Zeidler, D.L. (2014). Socioscientific issues as a curriculum emphasis: theory, research and practice. In N.G. Lederman & S.K. Abell (Eds.), *Handbook of research on science education*, *volume II* (pp. 697–726). 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. https://doi.org/10.1007/s11422-014-9578-z

Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–9. https://doi.org/10.1186/s43031-019-0008-7

Zeidler, D & Newton, M. (2017). Using a Socioscientific Issues Framework for Climate Change Education: An Ecojustice Approach. In D. Shepardson, R. Roychoudhury, & A. S. Hirsch (Eds.), *Teaching and learning about climate change: A framework for educators* (pp. 56–65). Routledge. https://doi.org/10.4324/9781315629841-5

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education, 21*(2), 49–58. https://doi.org/10.1007/BF03173684

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

Zeyer, A., & Dillon, J. (2019). The role of empathy for learning in complex Science| Environment| Health contexts. *International Journal of Science Education*, *41*(3), 297–315. https://doi.org/10.1080/09500693.2018.1549371

Ziman, J. (1994). The rationale for STS is in the approach. In J. Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 21 – 31). Teachers College Press.

Zhang, L., Tan, Y.Z.M., Adler, D.J. (2023). Teacher change in mainland China: Collaborative action research as a means of promoting secondary school teachers' engagement with the new curriculum reform. *Canadian Journal of Action Research, 23*(1), 3–20. https://journals.nipissingu.ca/index.php/cjar/article/view/530

Zimmerman, H. T., & Weible, J. L. (2017). Learning in and about rural places: Connections and tensions between students' everyday experiences and environmental quality issues in their community. *Cultural Studies of Science Education*, *12*(1), 7–31. https://doi.org/10.1007/s11422-016-9757-1

Zidny, R., Sjöström, J., & Eilks, I. (2020). A multi-perspective reflection on how indigenous knowledge and related ideas can improve science education for sustainability. *Science & Education*, *29*(1), 145–185. https://doi.org/10.1007/s11191-019-00100-x

Zussman, R. (2019, June 28). B.C. government set to launch mandatory immunization registration in September. *Global News.* https://globalnews.ca/new

Appendices

Appendix A: Complete Study Timeline

Below gives the Learning study timeline, including the month and dates, the activity pursued, participants, and the duration in hours. Each Learning study phase is given a number, corresponding to the list found in Chapter 3 (e.g., Planning Phase 1, to explore theoretical knowledge, the issue, and develop the object of learning. Planning Phase 2, for the design and administration or the pre-learning survey) and a letter, corresponding to the number of times that Learning study phases was covered (e.g., Planning Phase 1a on August 31st, 2020, kicked off the Learning study, while Planning Phase 1f on November 5th, 2020, was the final object of learning discussion for one teacher).

Learning study timeline.

Month	Date	Activity	Participants	Hours
Jun. 2020	18	School approval for the study	Head of School, Faye, Mike	1
Aug. 2020	31	Group Meeting 1. Pre-Learning study and Planning Phase 1a. Introduction, consent, timeline, general educational issue	Mike, Nicole, Dave, Faye	1
Sept. 2020	11	Mike Pre-Learning study interview	Mike	1.5
	17	Group Meeting 2. Planning Phase 1b. Objects of learning, theoretical knowledge	Mike, Nicole, Dave, Faye	1
	19	Dave Pre-Learning study interview	Dave	1.5
	24	Nicole Pre-Learning study interview	Nicole	1.25
Oct. 2020	3	Group Meeting 3. Planning Phase 1c. Objects of learning, Learning study in detail, theoretical knowledge	Nicole, Dave	1.5
	5	Faye Pre-Learning study interview	Faye	0.75
	6	Individual Support 1. Object of learning and survey design	Nicole	1
	8	Group Meeting 4. Planning Phase 1d. Objects of learning, Learning study in detail, theoretical knowledge	Mike, Nicole, Dave	1
	8	Individual Support 2. Object of learning	Dave	0.5
	23	Group Meeting 5. Planning Phase 1e. Objects of learning, theoretical knowledge. Planning Phase 2a. Sharing survey data	Mike, Nicole, Dave, Faye	2
	30	Individual Support 3. Analyzing student data, lesson design, confirmation object of learning	Nicole	1
	30	Individual Support 4. Object of learning and survey design	Dave	1
Nov. 2020	5	Group Meeting 6. Planning Phase 1f. Objects of learning, theoretical knowledge. Planning Phase 2b. Sharing survey design. Planning Phase 3a. Lesson design	Mike, Nicole, Dave, Faye	1.5

	12	Individual Support 5. Object of learning and survey design	Mike	1
	19	Nicole Research Lesson 1 (section A1)	Nicole, Mike, Dave, Faye	1
	23	Nicole Research Lesson 2 (section A2)	Nicole, Mike	1
	23	Individual Support 6. Research lesson debrief	Nicole	0.75
	24	Nicole Research Lesson 3 (section B1)	Nicole, Dave	1
	26	Nicole Research Lesson 4 (section B2)	Nicole, Mike	1
	26	Individual Support 7. Research lesson debrief	Nicole	0.5
	30	Nicole Research Lesson 5 (section A3) Nicole Research Lesson 6 (section B3)	Nicole, Mike, Dave	1
Dec. 2020	8	Group Meeting 7. Reflection Phase 1a.	Mike, Nicole, Dave	1.5
	14	Individual Support 8. Lesson design (based on Reflection Phase 1 and survey data from Planning Phase 2b)	Mike	1.5
	17	Individual Support 9. Lesson design, object of learning	Dave	1
Jan. 2021	12	Group Meeting 8. Planning Phase 3c. Lesson Design, object of learning	Mike, Nicole, Dave, Faye	1.5
	15	Dave Pre-Lesson 1.	Dave	1
	21	Individual Support 10. Lesson design (based on pre-lesson taught 15 Jan)	Dave	1
	21	Individual Support 11. Knowledge dissemination	Nicole	1
	26	Dave Research Lesson 1	Dave, Nicole, Mike	1
Feb. 2021	2	Dave Research Lesson 2	Dave, Nicole, Mike, Faye	1
	2	Individual Support 12. Research lesson debrief	Dave	1
	11	Mike Research Lesson 1 (section A1)	Mike, Nicole	1
	16	Dave Research Lesson 3	Dave, Nicole, Mike	1
	16	Mike Research Lesson 2 (section B1)	Mike, Dave	1
	17	Mike Research Lesson 3 (section A2)	Mike, Dave	1
	18	Mike Research Lesson 4 (section B2)	Mike, Nicole	1
	18	Dave Research Lesson 4	Dave, Nicole, Mike	1
	19	Mike Research Lesson 5 (section A3)	Mike, Nicole, Dave	1
	22	Mike Research Lesson 6 (section B3)	Mike	1
	22	Dave Research Lesson 5	Dave, Nicole, Mike, Faye	1
	23	Mike Research Lesson 7 (section A4)	Mike, Nicole	1

	23	Individual Support 13. Research lesson debrief	Mike	0.25
	23	Group Meeting 9. Reflection Phase 1b.	Mike, Nicole, Dave, Faye	1
	25	Mike Research Lesson 8 (section B4)	Mike, Nicole, Faye	1
	25	Individual Support 14. Research lesson debrief	Mike	0.25
Mar. 2021	1	Individual Support 15. Research lesson debrief	Dave	1
	2	Mike Research Lesson 9 (section A4)	Mike, Nicole, Faye	1
	4	Mike Research Lesson 10 (section B4)	Mike, Nicole	1
	5	Group Meeting 10. Reflection Phase 1c.	Mike, Nicole, Dave, Faye	1.5
Apr. 2021	1	Group Meeting 11. Reflection Phase 1d.	Mike, Nicole, Dave, Faye	1.5
	26	Mike Post-Learning study interview	Mike	1.5
	29	Faye Post-Learning study interview	Faye	0.75
May 2021	3	Dave Post-Learning study interview	Dave	2
	11	Nicole Post-Learning study interview	Nicole	1.5
June 2021 to May 2022		Knowledge dissemination efforts		

Appendix B: Descriptions of Learning study meetings

A narrative account of Learning study meetings. Group Meeting 2 is presented in Section 3.3.2.1.

School Approval

School approval for the study was obtained in June 2020 following Research Ethics Approval by The University of British Columbia. The meeting with Faye (school administrator), Mike (Science Department Head), and the Head of School ensured that all science teachers at Cranberry High would be invited to participate and that the study aligned with the school's mission. Following the study's summer advertisement, two additional teachers decided to join (Nicole and Dave). All participants were then sent a 'Learning study outline' (Appendix C) detailing a rough introduction to the work as well as readings to support the group. Readings were sent in June rather than at the beginning of the school year to offset the busy opening weeks of the term.

Group Meeting 1

In Group Meeting 1, general introductions and the aims of the study were presented before participants had opportunities to ask questions and air grievances. Here, the idea of separate objects of learning for each teacher was floated by Mike and Nicole as a crucial modification given course schedules. Once agreed, all participants signed consent forms.

Following, the realities of teaching during COVID-19 were brought up by Faye. After a semester of emergency online teaching (Spring 2020), participants were excited to be back in person but hesitant about the year ahead. We agreed to have high levels of respect and understanding for each other's comfort levels. It was articulated the Learning study would always come behind the safety of students, staff, and faculty at the school. The study was an exciting add-on to the year, or as Mike put it “Not urgent, but potentially earth-shattering” (Group Meeting 1).

I then introduced the general theme of SRSE and the SSI components in the revised BC curriculum, and I described my own experience engaging with teacher collaborative inquiry. These experiences were used to introduce the Learning study approach and my role in the study, including facilitator of discussions; meeting organizer; and knowledgeable other regarding SRSE, data collection and analysis techniques, and resource acquisition. The element of the revised BC curriculum most in line with SRSE was agreed upon as “Developing students ability to bring a scientific perspective, as appropriate, to social, moral, and ethical decisions and actions in their own lives, culture, and the environment” (BCME, 2018).

To close, the teachers discussed possible topics for exploration in line with SRSE and the revised curriculum, initially pulling from the topic list provided in the Learning study outline. The aim was to have a topic to discuss at the next Group Meeting. Of note was the teacher’s hesitancy towards Henrietta Lacks and the racialized practices of cancer research (Skloot, 2017). There was a sentiment that SRSE should not deal with race at Cranberry High, given elevated tensions brought on by the recent murder of George Floyd and the accompanying Black Lives Matter movement (e.g., Boudreau et al., 2021; Green, 2021). Following this, the teachers were reminded that the topic was always theirs to choose.

Group Meeting 3

Group Meeting 3 had only Nicole and Dave in attendance owing to personal emergencies. After I discussed the Learning study approach, Nicole and Dave began developing their objects of learning. Nicole had come with several she had made, but Dave felt they did not go ‘deep enough’ into students’ inner thought processes, hinting at the eventual idea of ‘transformation’ as a prime SRSE outcome. Nicole was hesitant about this critique, wondering how she would be able to measure transformation on a post-lesson survey. Through this process of refinement, her object of learning became: developing students’ ability to propose and evaluate local and global level actions to reduce harm from pandemics based on scientific theory. Nicole justified this focus based on the direct ties to the curriculum but also, its potential for students to reflect on the school’s pandemic-based actions. She hoped this focus might propel students to keep their masks on, social distance consistently at lunch, and wash their hands, all to prevent the students from infecting others or themselves.

The conversation shifted to Dave’s object of learning. He did not see how the revised BC curriculum and SRSE could mesh with an already saturated Advanced Placement course. Advanced Placement courses, or AP courses, are courses designed by the American College Board. They can often be substituted for college credits and are typically seen as more ‘rigorous’ high school courses (Sadler et al., 2010). Nicole led a discussion showing how curricular expectations did not need to be changed or added to enact SRSE, noting carefully that they were doing this project to understand more fully what SRSE *could* be – not to implement some predetermined goal. This propelled Dave to forward several objects of learning.

The conversation then turned to discussions around the traditional science education culture at Cranberry High. Dave and Nicole recognized that students and other science department members might be skeptical of SRSE because of its novelty. For students, it moved away from forms of teaching and learning centred on lectures and tests, introducing new means and ends of science education. For teachers, it expanded what science education could be, and to what uses it could be directed. Nicole closed the meeting by indicating her research lessons should occur before December. She felt that there was still much to do before her lessons could get underway (e.g., finalize, administer, and analyze the pre-learning survey). As such, an Individual Support Meeting (ISM) was offered to work toward these goals.

Individual Support Meeting 1

Prior to the individual support meeting (ISM 1), Nicole indicated she had received feedback from Mike over email regarding her proposed object of learning. Based on his feedback, it remained unchanged. Subsequently, the 3-VSL was drawn on and Nicole and I brainstormed possible pre-lesson test questions and lesson features.

Group Meeting 4

Group Meeting 4 was with Mike, Dave and Nicole. The meeting began by discussing the Learning study steps in detail, drawing from the Clarke and Erickson (2006) and Pang and Runesson (2019) readings with which the teachers engaged. Following, Nicole represented her object of learning (originally refined in Group Meeting 3 with Dave and through email with Mike), and the group had time to contribute to the design of her pre-lesson survey. A few modifications were made before the group engaged in a discussion around Mike's object of learning. Here, they drew from the 3-VSL, and its explicit inclusion of the critical Vision (i.e., Vision III), to justify Mike's interest in engaging students in personal actions to mitigate climate change. Mike felt his past climate change unit focused too heavily on technological innovations. He felt the implication was that personal action might not be needed since technology would provide climate change solutions. The group agreed and felt Mike's interest in personal actions was needed for climate change mitigation. Through his conversation, Mike's object of learning became: developing students' ability to understand the why of their actions towards living a life with a lower carbon footprint. Dave concluded the meeting with a renewed focus on his object of learning. He brought up his continued hesitancy to base it around his AP Environmental Science course. An individual support meeting (ISM 2) was requested by Dave after Group Meeting 4 to support him further.

Individual Support Meeting 2

In the ISM 2, Dave brought up broad educational goals to clarify some of his thinking about his object of learning. Dave felt he needed to have a more refined set of ideas to present to the Learning study given their reduced capacity to meet. School schedules were compressed, shortened, or cancelled from pandemic restrictions. Dave wanted time to work through some of his ideas in a supportive manner. In this meeting, I served as a scribe and critical friend. I asked questions about why he might want to pursue certain ends in the Learning study and documented those ideas. Dave wanted to use the documentation to clarify his own thinking and to then share with the group.

Group Meeting 5

Group Meeting 5 was the first meeting conducted indoors, socially distanced rather than outside. The meeting opened with a brief overview of the past four meetings. This included a review of the 3-VSL to highlight the varied Vision III goals the teachers were pursuing. Nicole shared her students' pre-lesson survey data, which was administered between Group Meeting 4 and 5. Nicole presented her initial analysis of the data and the remaining group members added their own interpretation. The teachers interpreted the data as many students being unable to propose diverse pandemic control measures, that their evaluation of them was mainly in personal terms (e.g., the main con of mask-wearing was that it was 'uncomfortable'), and that their scientific understanding of the pandemic was wanting. This gave the group direction on the suitability of Nicole's object of learning and how to design Nicole's lessons. Several lesson features were forwarded (e.g., focusing on the science of pandemic control measures through interactive videos and incorporating diverse perspectives of the impacts of COVID-19 on different populations through future webs) that she considered and adapted based on her knowledge of her students.

The conversation then turned to Mike. He elicited the group's feedback on the choice of 'carbon footprint' in his original object of learning, and it was changed to be more specific. 'Carbon footprint' was changed to carbon emissions. Mike also explained his personal investment in the issue. Dave then presented some of his ideas from ISM 2. The conversation then turned pragmatic as the group realized mid-October was a crucial point in the academic year. With report cards and parent-teacher interviews around the corner, a public holiday (Remembrance Day), and winter holidays approaching, the teachers felt they needed to make more progress toward their research lessons. Through more group discussion, and feeling time constraints, Dave came to the object of learning of: developing students' ability to analyze and discuss the scientific, social, ethical, and environmental implications of emergent research in the field of Earth Systems and Resources.

Individual Support Meeting 3

Nicole used the individual support meeting (ISM 3) to make final modifications to the lessons designed in Group Meeting 5. Nicole also shared a vignette of a way in which her SRSE exploration was impacting her teaching outside of the typical research lesson sequence (Appendix J). These are experiences the teachers felt were related to the Learning study but not directly captured in research lessons or with formal observations. There was a moment a student was refereeing COVID-19 as the ‘China Plague,’ a moniker Donald J. Trump, then President of the United States of America had been using in news media. Nicole indicated that the problematic nature of this term was tackled head-on, and she felt like she was finally engaging in SRSE. Nicole commented that without the prior meetings, she would not have engaged with a student in this way.

Individual Support Meeting 4

The next individual support meeting (ISM 4) was directly after ISM 3. Dave wanted to further discuss his object of learning and decide on a spot for it within the AP curriculum. Once the curricular area was chosen, Dave formulated how to implement the object of learning. He sought to do so through a ‘Research Café’ format – something he had run previously. Students would read an academic article and present the findings to the class, tying it with the curriculum before leading a discussion. Dave adapted this format to include his object of learning, placing more focus on the social, ethical, and environmental implications of the article. The meeting ended with Dave and me brainstorming some questions for his pre-lesson survey and summarizing some Research Café features which could be presented at the next group meeting.

To end October, Mike made a presentation to another high school in the area regarding his upcoming climate change unit. He sent an email to me indicating the presentation was a ‘quasi-Hodson approach to action’ he took with fellow teachers. In his presentation, the 3-VSL was featured as a tool to think about climate change education in a way which supported students in mitigating and responding to the problem rather than just learning about it. Like Nicole's vignette from ISM 3, this is another instance of Learning study meetings having an impact on teachers' practice before the research lessons were taught.

Group Meeting 6

Group Meeting 6 was the first virtual meeting held on Zoom (an online video-conferencing software). It was necessary given the rising COVID-19 case numbers. Nicole began the meeting by showcasing her lessons, now finalized based on Group Meeting 5 and ISM 4. The group provided feedback and suggestions. Conversations included how Hodson's (2014) work had made its way into the lessons (e.g., framing COVID-19 impacts around economic, social, political, and environmental considerations [p. 70 & 81]) and the use of pre-learning survey data was best leveraged. Faye closed this section with an apology that I would no longer be allowed to visit the school, at least until March break. The day prior to Group Meeting 6 new COVID-19 cases emerged at the school, and new policies were put in place. The choice was to have me 'Zoom In' to all research lessons so I could observe and take notes, in addition to re-watching the lesson audio-video recordings.

The conversation around Nicole's lessons ended with me coordinating which teachers were available to observe which lessons (Nicole had two sections of Science 8, and her research lessons spanned three classes each) and drawing teachers' attention to an observational prompt document (Appendix D) which they could use to guide their lesson observations. The prompt document drew focus on what students were learning as well as the teaching strategies employed (Pang & Runesson, 2019). Importantly, while the teachers' pedagogies are focused on, these acts are not separated from student learning. The two are examined together (e.g., Tan et al., 2019b).

Following this, Dave presented his object of learning for continued refinement, and the group worked on his pre-lesson survey, offering recommendations on how to cut it down and focus on what would be pertinent to design the lessons. Dave also presented his Research Café idea. The meeting closed without getting to Mike's Learning study progress, and an individual support meeting was planned as a result.

Individual Support Meeting 5

ISM 5 was the first one-to-one meeting with Mike. He was keen to connect his object of learning to a pre-lesson survey and we began to brainstorm questions accordingly. Like Dave's ISM 2, this meeting was convened to ensure future Group Meetings could proceed efficiently and focus on broader ideas rather than particulars (e.g., the reasoning behind Mike's survey question as opposed to the survey questions themselves). The choice was made to illicit survey feedback asynchronously from Dave, Faye, and Nicole since Nicole's research lessons were being taught the following week and report card deadlines were approaching. After the call for survey feedback was sent, Mike revealed his intention to base his climate change unit around three modules. He noted that the first and second would cover a nine-lesson set focused on conceptual and contextual literacy Visions (e.g., Vision I and II) and their relationship. Module One was titled 'Earth's Systems' and Module Two 'Humans as part of Earth's systems.' Mike noted the final module would encapsulate the research lessons. Mike felt this allowed him to plan for his unit now, set to begin in January, while still using student survey responses to design the final module portion and refine his object of learning with the Learning study group.

Following ISM 5, Nicole taught her research lessons. A narrative account of the lessons is provided in Chapter 4, pooled by the categories constructed in the phenomenographic analysis (i.e., lessons in the same category from each teacher are presented together). A lesson-by-lesson account is given in Appendix E. After logical points in the lesson series, Nicole and I met socially distanced, outside the meeting room (and under umbrellas since it was raining), as a post-lesson debrief. Two such meetings (ISM 6 and ISM 7) occurred. This was deemed appropriate given my inability to be at the school to gather immediate interpretations of how she felt the lessons went (because of COVID-19 restrictions). The practice of having a post-lesson conference with the Learning study research-facilitator is observed in other Canadian-based Learning study's (e.g., Tan et al., 2019b).

Individual Support Meeting 6 and 7

ISM 6 focused on the first two lessons of the three-part series taught to only one section of Science 8. ISM 7 focused on the remaining lessons and changes made from ISM 6 reflecting the iterative nature of Learning study classroom research (Figure 3). In these meetings, the observational prompt document (Appendix D) guided our reflection. Nicole felt that the classes did not go well owing to students' inability to stay on task. Through further conversation, Nicole felt that the style of learning she expected her students to pursue (e.g., based on collaboration, reading articles, making presentations) was likely foreign to them and precipitated behavioural challenges. Nicole developed 'on-task checklists' for the next section of Science 8 to engage with the lessons, as well as a lesson introduction blurb explicitly stating the new learning the students would encounter. The hope was these practices would aid students' in staying on task.

Group Meeting 7

Group Meeting 7 was dedicated exclusively to the reflection phase of Nicole's lessons. Notably, the teachers had been engaging in in-class instruction while masked, socially distanced, and often through layers of plexiglass for 61 days. The teachers brought up these conditions, and time was given for commiseration. The reflection phase of the Learning study provided the teachers with space to evaluate lessons based on the theoretical perspectives explored. As an example, Nicole forwarded that in the final lesson, students brought up a change they wished to see in the school's pandemic response which they brought to a school administration member. This demonstrated an 'action' they took aligned with the critical literacy Vision (Vision III). The change they wished to see was based on the science they learned of viral spread from the first research lesson, highlighting the continuum between Vision I and III (e.g., they wanted the desks to be placed even further apart at lunch to block the spread of potential COVID-19 containing droplets and they knew administration were the ones capable of making that change). Upon hearing this in the Group Meeting, Faye arranged for a separate conversation to update the school's policies.

The group also forwarded good pedagogical strategies that appear to positively impact student learning. Nicole explained her teaching choices, some of the challenges she faced, and recommendations for Mike and Dave as they solidified their research lessons. The group suggested improvements throughout and brainstormed options for how similar classes could proceed. To close, two more ISMs were planned by Mike and Dave to ensure they had all they needed before the winter holidays.

Individual Support Meeting 8

Mike wanted ISM 8 to focus broadly on rough elements of the research lessons he wanted to share with the group following the holidays. Mike felt a standout of his climate change unit would be the incorporation of an ‘epilogue’ which invited students to pursue some climate change mitigation action they deemed appropriate and had developed through the research lessons. A confluence of factors led to this feature inclusion. Mike indicated that having time to ‘sit’ with Hodson’s work was important to mull over ideas. Likewise, he noted that Nicole’s classes (presented in Group Meeting 7) provided evidence that students wanted to engage in some action without being explicitly directed to do so. This drove him to consider how else he could support a greater diversity of student goals.

Individual Support Meeting 9

Dave directed ISM 9 to focus on his pre-lesson survey results and how those might influence lesson design. On December 15th, Dave explained how he had taken an SRSE approach to a roundtable discussion on farming techniques. There, students discussed the ethical implications of new farming technologies in relation to social, economic, and environmental challenges. Like Mike and Nicole before, Dave was integrating Learning study ideas into his classes before his research lessons were conducted. Through this farming example, Dave felt his students were lacking in some areas needed for his research lessons. This was corroborated by his interpretations of the survey data. He felt very few students were able to give ethical or social implications of a variety of issues (e.g., less than half of the students could define ‘ethical implication’). Based on the December 15th lesson and survey data, Dave felt it might be necessary to engage in a pre-research lesson to prime his students, and himself, for the full research lessons to follow.

Dave made plans to forward his lesson ideas during the first meeting back after break. Due to the pre-lesson, Dave also had to shift his object of learning to a different AP Environmental Science unit. The object of learning became: developing students' ability to analyze and discuss the social, ethical, and environmental implications of emergent research in the *Unit Land and Water Use*.

Group Meeting 8

Mike shared his pre-lesson survey data and rough elements of his research lessons in Group Meeting 8. The group provided feedback and suggestions, fleshing out crucial parts of the lesson series, like how carbon emissions could be calculated and what scaffolds might be needed for students to think of a 'big picture' message for their culminating assignment. Special attention was paid to Mike's epilogue idea floated in ISM 8. Now labelled 'Hope To,' the idea was to have the entire climate change unit culminate in some student-directed action to mitigate climate change. All members enthusiastically responded to this addition. For some, the invitation stance was a softer way to introduce action than the 'Hodsonian' approach, but for others, there were questions as to if students would take up the call. In the opening climate change unit (i.e., Module One on Earth's System's), Mike relayed that the majority of his students, when asked, wanted some form of action they could take as an outcome of the unit. Mike insisted he would not have noticed these students' wants without the concepts brought up by the 3-VSL. Backed by student wants, also evident in Nicole's research lessons, the group was confident some students would dare to 'hope to.'

Dave then presented his initial interpretations of his pre-lesson survey data, rough elements of his research lessons, and his object of learning. The group provided feedback and suggestions, fleshing out a modelling approach to Dave's Research Café that might address the lack of social and ethical experiences found in the pre-lesson survey. Dave recounted his class on December 15th and indicated his students shared challenges Nicole had mentioned during her research lessons (e.g., when students were tasked with collaboration, behavioural problems arose because they were unfamiliar with those skills). Nicole, Mike, and Dave felt an SRSE 'warm-up' lesson beginning the modelling approach would be a way to ease into the research lessons.

Mike and Dave then made comparisons between their topic choices. Mike's was climate change and Dave's Research Café let students choose their topic. The discussion revolved around how topic choice might impact certain Vision III goals and specifically those goals centered on action. On one hand, a firm topic might allow for more scaffolding for eventual action – or any of the goals – and at the very least, provide a shared understanding of the harm caused by the issue. On the other hand, student choice and voice might lead to action more because it is based on student interest, regardless of shared understanding. Nicole brought up a time she was 'forced' into an action project by a teacher and felt no more inclined to engage in similar actions in the future, supporting the latter argument. The teachers sat on these ideas. I closed the meeting by coordinating which teachers were available to observe which lessons and drew teachers' attention back to the observational prompt document (Appendix D).

Following Group Meeting 8, Dave and Mike taught their research lessons. A narrative account of the lessons is provided in Chapter 4. A lesson-by-lesson account is given in Appendix F and G for Dave and Mike, respectively.

Individual Support Meeting 10

ISM 10 was held on a 400-metre track in the school as Dave paced around it. The meeting focused on what Dave felt was a resounding success of his pre-lesson on the tragedy of the Tragedy of the Commons. He indicated that students participated enthusiastically as social and ethical dimensions were discussed, debated, and tied to the AP curriculum. The controversial topic of showing how the founder of the Tragedy of the Commons was a known racist and eugenicist stoked student engagement and Dave commented on his student's increased engagement, fun, and lasting conversations the class fostered. As an example, Dave noted that a little under half of his class reconvened after school to further their class-based discourse, disrupting his extra-help session for his Grade 11 Chemistry students.

Despite this, Dave indicated classes like that would have to be a minority given the AP curriculum and expectations of the school community. He felt the pressure of the AP exam, noting while the learning skills developed were important, they lacked the explicit conceptual focus the AP exam required. From this tension, Dave developed further modifications to the Research Café, including more attention to the AP curriculum and the need for students to explicitly tie their projects to standards found in the AP exam.

Individual Support Meeting 11

Nicole convened ISM 11 to support her knowledge dissemination phase of the Learning study. A handout was developed for the 30 teachers attending her session, titled 'Integrating Content and Competencies in Senior Science through Socio-scientific Issues.' Nicole felt it would be distracting to forward SRSE when there was so much else to say in the presentation. For example, she noted that the group routinely mentioned the 3-VSL. From this focus, she wanted the presentation to highlight the 3-VSL approach to SSI instruction and her research lessons as a manifestation of that approach. Nicole reflected that the conference presentation was a suitable way to solidify her learning, allowing her to reflect deeply on what was essential in her classes.

Individual Support Meeting 12

ISM 12 was held directly after Dave's second research lesson in which he modelled the Research Café the student would eventually engage with. In this post-lesson conference, Dave reflected on the difficulty of tying the 3-VSL together in one project. He felt his own presentation was lacking in coherence and focus. He decided that more prep time should be given to students to fully tie in all the aspects of their presentations. The prep time resulted in a class dedicated to individual student work (termed a 'work period'). This explains the temporal gap between Dave's Research Lesson 2 (February 2nd) and Research Lesson 3 (February 16th).

Individual Support Meeting 13

ISM 13 was a short debrief directly following Mike's Research Lesson 7. Mike outlined broad summaries of what went well and what could be modified, including pacing and more evocative prompts to get students talking. Like Nicole and Dave, Mike commented on the lessons' ability to engage students, noting typically quieter students, or students that had struggled all year were engaged and succeeding. He also noted he had to add a work period for student presentation development, like Dave.

For Mike's research lessons, debriefs were attempted after each lesson was observed on Zoom, but course scheduling meant he had to be off to another class immediately. Occurring at the end of February 2021, these lessons matched the crunch point of November 2020. Report cards and parent-teacher interviews were nearing, and March break provided a tantalizing respite from the hardships of pandemic-based teaching. Course schedule and the fact that Mike and Dave had overlapping research lessons (e.g., from February 16th to 23rd, 2021, two lesson observations occurred each day) meant that the researcher lesson debriefs had to be consistently postponed. This proved logistically difficult for audio-video resources; I had to meet with school facility personnel or Nicole to swap equipment and batteries each evening after school.

Group Meeting 9

Group Meeting 9 was like Group Meeting 7 but with a focus on Dave's research lessons. The group used questions from the observational prompt document (Appendix D) to probe and add to Dave's interpretations of how the lessons went, what he deemed successful and wanting for adaptations, and how the 3-VSL resonated with students. Nicole, Mike, and Faye offered their suggestions for improvement. Notably, all teachers commended Dave for tackling SRSE in an AP course. Initial post-lesson survey data was also shared by Dave to further highlight the impacts the classes had on students (e.g., they could *all* now name an ethical implication).

In these discussions, the main stand out was an agreement that Dave's lessons provided an opportunity for transformation, and that further time should be used to follow up with the students about the personal challenges (these were a stance students took on a harmful SSI and an action they proposed to mitigate it). Through research, presentations, and discussion, Mike and Nicole felt that many students appeared to be thinking about their daily practices differently (e.g., thinking about university acceptance in terms of 'green' policies or making small commitments to 'go vegan' two days a week). Faye noted they also seemed primed to translate those differences to something tangible (e.g., school battery recycling stations). The group felt that many personal challenges could be implemented at the school, and it was agreed future iterations should give time and space to allow continued student exploration.

The group recognized this shift in thinking: they now wanted to follow and support students on their action journeys. I brought up socially *irresponsible* science education as a catalyst for discussion. From there, Nicole began to point out the different ways each group member had enacted types of 'Hodsonian action' that they felt most comfortable with. Mike noted that the comfort was also constantly shifting. Nicole shared the success of her conference presentation to close the meeting.

Individual Support Meeting 14 and 15

ISM 14 was another post-lesson conference with Mike, immediately following his research lesson. Mike was deeply impressed by the students' presentations and the depth and breadth of actions they proposed to lower their carbon emissions. Mike expressed hope for the 'Hope To' invitation and he was excited at the prospects of students following through on their intentions and presenting them on Earth Day 2021 (an annual event to support environmental protection [Earth Day, 2023]). ISM 15 was called by Dave as a space to reflect on the tensions between SRSE and an AP course.

Group Meeting 10

Group Meeting 10 was the final meeting before March break and represented the final reflection phase of specific research lessons. Like Group Meetings 7 and 9 before, this meeting focused on Mike's research lessons. Mike came well prepared for the meeting, having written answers he shared via screen share on Zoom to the observational prompt document (Appendix D). Mike led the discussion regarding how he felt the lessons went (question 7, Appendix D), memorable instances (question 8), modifications (question 9), and new insights (question 10). Dave, Nicole, and Faye contributed when appropriate, primarily highlighting the quality of student presentations and their diverse plans to lower their carbon emissions. All group members felt the scope of the unit set the students up well for deep mastery of the science behind climate change, which in turn propelled students' project diversity. Plans were laid for Mike's third iteration of his climate change unit, building off the success of the current one.

Other points of note included Mike's candidness about the 3-VSL. He heralded it as something to remember long after the Learning study ended. Showing his thinking, Mike presented a three-part Venn-diagram highlighting his evolving use of the 3-VSL. The discussion that followed was a theorizing of the 3-VSL. That is, the teachers made alternating points about the utility of turning each Vision into overlapping circles, noting the pedagogical implication of having each Vision equally represented in every unit, rather than pushing in one direction. Finally, Mike expressed his want to further the 'Hope To' invitation to better support student action. His ideas included providing case studies of actions already taken by youth regarding the climate crisis. Nicole and Faye wondered if combining the intentions of 'Hope To' with existing school groups could be a place the invitation could live and be further supported.

Group Meeting 11

Group Meeting 11 was a focused reflection on teachers' entire experiences in the study. I produced a reflective prompt document (Appendix) that was used to structure the meeting and to help develop the final interview questions. Each prompt was covered sequentially, focusing on key aspects of the Learning study: learning about SRSE, about pedagogy, and about 3-VSL. Professional development aspects of the Learning study, such as collaboration, variation of the typical approach (e.g., three different objects of learning), use of student data, and inquiring into their own and other classes were also forwarded. The meeting concluded with the scheduling of final interviews.

Closing

By the end of the Learning study, a summary was written and distributed to the faculty at Cranberry High (in June). Further plans for conference presentations materialized throughout the Summer of 2021. Led by Mike, one was given to a provincial science teacher group the following Fall (October 2021). Led by Nicole, another was given at a national conference the following Spring (May 2022).

Appendix C: Learning Study Outline

Learning study outline document given to participating teachers before Group Meeting 1. It contains (1) a rough outline of the Learning study focus and process, (2) a reading guide providing outlines for each resource presented and read by the teachers, and (3) potential socioscientific issue (SSI) topics the teachers could pursue in their classrooms.

Socially Responsible Science Education: Professional development for science teachers

Focus	This PD is a study of two things: (1) ways to do SRSE best and (2) PD approach to support one. My dissertation focuses on teachers learning about SRSE and their own practice throughout the PD. The aim is to see if the PD approach would be useful for future PD and to foster thinking about SRSE.

Specifics	**SRSE** seeks to use the foundational conceptual knowledge taught in most science classes to enable students to see the influences of science on society (and vice versa) and encourage them to reduce any harms these influences may have on individuals, societies, and environments.
	
	Learning Study is the PD approach. It is a variant of action research where teachers collaborate to address an educational goal in a systematic way.
	
	Constant features of the approach:
	• Object of learning – the goal of the LS.
	  o E.g., scientific argumentation, climate optimism
	• Process – iterative planning, teaching research lesson(s), reflecting, and sharing
	• Theory – to frame the process
	  o E.g., conceptual change. We will use Three Visions of Scientific Literacy
	• Collaboration – throughout the process
	
	Feature which can vary:
	• What the object of learning is – can differ inside the LS but generally around the same theme. This keeps collaboration focused and fruitful.
	  o E.g., same part of the curriculum, same theme of optimism, etc.
	• Methods to study – generally some version of pre/post-test. However, interviews or student reflections can be employed as well
	• The research lesson – how the lesson(s) are taught will vary

Structure	Broken into meetings, 'homework', and interviews. Estimated time is September to March-break. Meetings ~1 - 1.5 hr occurring every two-ish weeks depending on schedules. More meetings are always available.
Homework	Includes readings before certain meetings, the design of the research lesson(s), teaching the research lesson(s), and evaluating the results. Also watching other members' research lessons.

Reading Guide

Socially Responsible Science Education. For the September meetings.

- Hodson (2014). This is one of the longer pieces to be presented in which Derek Hodson outlines his vision for the future of science education. He has previously made the case that science education ought to help students learn science (e.g., concepts and principles), learn about science (e.g., how it is done, its history, and its interaction with society), and do science (e.g., engage in scientific inquiry). He now makes the case that engaging in action on science/technology-related matters of social, economic, environmental and moral-ethical concern is a crucial final component. As Hodson notes in the opening: If you are not part of the solution, you are part of the problem.

- NSTA – Next Gen email. This simple email was eye-opening for me. The National Science Teacher Association is historically set on more traditional science education goals and pedagogies. This email, in the wake of Black Lives Matter protests and others, demonstrates a shift in the thinking of some of the leading science associations in North America. Following the articles they mention in the email, some examples to infuse social responsibility in the science classroom can be found after the references below.

- Levinson (2018a). This one is more of a step-by-step guide, with examples, to engage in some of the practices Hodson (2014) and the NSTA email were advocating. There are many more such frameworks out there, and I am not suggesting adherence to any of them. However, the article gives a good glimpse of a few ways different approaches can materialize in a classroom.

- Levinson (2018b). This final paper is more of a 'if you want more' piece. It is dense, has a lot of terms, and a fair amount of philosophy (all things I think make it amazing!). For me, the standout portions are the way the author frames the introduction (p. 522 – 523) as well as the tangible examples (p. 531 – 535).

The Learning Study. For the September/October meetings.

- Clarke & Erickson (2006). This is probably my favourite teacher research piece out there. I think it does a really good job of framing succinctly what teacher research is and why it is so needed in education. The Learning study we will be engaging in is a related approach.

- Pang & Runesson (2019). This is a contemporary piece outlining the basics of Learning study and its current developments. Since very few Learning studies have ever been done in Canada, we have a lot of room to modify the approach based on the WPGA context. As an example, the paper notes that 'Variation Theory' must be used in the learning study (p. 162, para. 3). We will not be doing this. As such, the paper serves as a brief introduction. I would suggest reading p. 162 – 164, para. 2.

- Kincheloe & Steinberg (1998). This final paper is, again, more of a 'if you want more' piece. It is probably my second favourite to the Clarke and Erickson (2006) piece. Like the Levinson (2018b) article, it is packed with terms and philosophical musings that I find delightful. They attempt to showcase the importance and necessity of teachers as scholars and sharing their research.

Theory for Learning Study: Three Visions of Scientific Literacy.

- For Group Meeting 2. 3-VSL as a theory to learn from and with. In our Learning study, it will provide theoretical perspectives (similar to variation theory from above).

References

Clark, A. & Erickson, G. (2006). Teacher inquiry: What's old is new again. *BC Educational Leadership Research, 6*, 1–8. https://blogs.ubc.ca/stevemcg/files/2015/09/Clarke-Erickson-2006.-Teacher-inquiry-Whats-old-is-new-again.pdf

Hodson, D. (2014). Becoming part of the solution: Learning about activism, learning through activism, learning from activism. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education* (pp. 67–98). Springer. https://doi.org/10.1007/978-94-007-4360-1_5

Kincheloe, J. L., & Steinberg, S. R. (1998). Lesson plans from the outer limits: Unauthorized methods. In J. L. Kincheloe & S. R. Steinberg (Eds.), *Unauthorized methods: Strategies for critical teaching* (pp. 1-23). Routledge. https://www.routledge.com/Unauthorized-Methods-Strategies-for-Critical-Teaching/Steinberg-Kincheloe/p/book/9780415918428

Levinson, R. (2018a). *Real*ising the school science curriculum. *The Curriculum Journal*, *29*(4), 522–537. https://doi.org/10.1080/09585176.2018.1504314

Levinson, R. (2018b). Introducing socio-scientific inquiry-based learning (SSIBL). *School Science Review*, *100*(371), 31–35. https://www.ase.org.uk/system/files/SSR_December_2018_031-035_Levinson_0.pdf

Mackenzie, A.H. (2020). Social justice in the science classroom. *The Science Teacher, 87*(7). https://www.nsta.org/science-teacher/science-teacher-march-2020

Pang, M.F., & Runesson, U. (2019). The learning study: recent trends and developments. *International Journal for Lesson and Learning Studies, 8*(3), 162–169. https://doi.org/10.1108/IJLLS-07-2019-093

Potential Topic List

Social responsibility in science class examples from Mackenzie (2020) (NB: U.S. focus but highly adaptable and applicable)

- Food Deserts
- Environmental Racism
- Tuskegee Syphilis Study
- The Opioid Epidemic
- The 80s Crack Epidemic and Fallout
- Industrial Dumping
- Asthma in Urban Spaces
- Denial of Green Space
- Lead in Drinking Water
- Henrietta Lacks (Racism in Cancer Research)
- Abnormally High Rates of Cancer in Black Populations
- Vaccines and the Anti-Vaccine Movement
- Effects of the Foster System on Development
- Effects of Solitary Confinement on the Brain
- Incarceration and Institutionalization Complex
- Science and Gender Identity
- Human Experimentation/Exploitation
- Partial/Whole Human Cloning
- Genetic Discrimination
- Eugenics and Racialized Genocide
- Population Control
- Population Growth and Resource Management
- Science of Language and Lingual Oppression
- Gender Bias and Sexism
- Mass Incarceration
- Search Algorithm Bias
- Prescription Opioid Abuse
- Third World Pharmaceutical Trials
- Mental Health and Treatment Disparity
- Science in Hip-Hop Music
- Access to Healthcare
- Infant Mortality
- Quality Housing and Health
- The Effects of Abuse and Trauma on the Brain
- Exclusion of Women/Minorities from Science

Additional topics

- Hodson (2014) broad topics (p. 70), specific topics (p. 81)
- Climate Crisis, in general
- Disproportionate effects of COVID-19 on various populations

Appendix D: Observational Prompt Guide

The observational prompt document given to the teachers to aid in structuring their lesson observations and post-lesson reflections.

Guiding questions for lesson observations and post-lesson conferences

For observations

Focus on student learning, 3-VSL, elements of SRSE, and effective pedagogical strategies

1. What was the intended learning object and how does it relate to SRSE?
   a. What instances of classroom teaching and learning were connected with the 3 Visions of scientific literacy (conceptual, contextual, critical)?
   b. How did students respond to each of the visions?
2. What were the students feeling and how did they connect with the learning that took place in the classroom?
3. What evidence is there that the students were learning?
4. Comparing the intended learning object (lesson plan and/or teachers' activity system), the teaching, and students' experiences of learning, what were the pedagogical strategies that were effective?
5. What other instances of classroom teaching and learning are worthy of mention? Why?

For post-lesson conference

6. How did the one teaching the lessons feel they went?
   a. Highlight pedagogical choices, insights, delights, challenges
7. What is worthy of mention from questions 1 through 5 for the observer(s)?
8. Discuss anything one might modify for future lesson(s) aimed at the same topic or outcome.
9. At this point, are there any insights into student learning, SRSE, or 3-VSL to carry forward into the next research lessons?

Appendix E: Lesson Descriptions for Nicole's Research Lessons

Lesson I	Lesson II	Lesson III
The aim of Lesson I was to deepen students' comprehension of the mechanisms and consequences of virus transmission, as well as the effectiveness of pandemic control measures in limiting transmission. To engage students, the SSI was employed as an attention-grabbing tool. Using infographics, students were able to visualize and discuss the various factors that contribute to viral transmission, such as droplet size. To further supplement their understanding, students were exposed to a variety of multimedia resources, including videos and websites, that delved into the scientific principles behind popular pandemic control measures. In small teams, students synthesized their knowledge and presented their findings in a series of informal class presentations. The next step was to focus on contextual literacy. Students were assigned to read one of four articles that examined the environmental, economic, and social impacts of COVID-19 as homework.	In Lesson II, students engaged in a collaborative activity where they shared their understanding of the impacts of various pandemic control measures, such as border closures and mandatory quarantine. To aid in their analysis, students utilized a visualization tool called a future web, which helped them to understand the direct and indirect consequences of a particular change. After creating their future webs, students came to a justifiable conclusion on whether a certain measure should be implemented or not and shared their findings with their peers. As an extension of the lesson, students were assigned to discuss their pandemic control measure findings with the adults they live with.	The final lesson centered on how students can take action based on what they learned, and if they feel a sense of responsibility towards any COVID-19 responses. The class began by sharing new perspectives and ideas from their conversations with adults. This led to a discussion where students reflected on their learning experiences throughout the set of lessons. The prompts for the discussion included: What actions can be taken now? Is there a sense of responsibility towards our COVID-19 response? What was learned throughout the lessons? The conversation was allowed to flow based on student interest. Students completed a post-lesson survey to end the class.

Appendix F: Lesson Descriptions for Dave's Research Lessons.

Pre-Lesson	Lesson I	Lesson II - IV
The Pre-Lesson focused on priming students for SRSE learning practices, such as engaging in discussions, constructing knowledge from articles, and working collaboratively. The SSI of cancel culture as it relates to scientific concepts was pursued through the Tragedy of the Commons. Addressing conceptual and contextual literacy, key concepts about the Tragedy of the Commons and how the framework has proliferated to influence economic, environmental, and societal policy and thinking were taught using curated videos and textbook readings. After ensuring students could demonstrate their understanding, the class read an article by Mildenberger (2019) titled *The Tragedy of the Tragedy of the Commons*. The article was chosen to stimulate critical literacy skills. It established that a developer of the Tragedy of the Commons, Garrett Hardin, was a known "racist, eugenicist, nativist, and Islamophobe" (p. 5). Furthering critical literacy, the class then engaged in open discussion around cancel culture as it pertains to scientific discovery and concepts, the cultural influences of personal ideologies, and the framing of concepts developed by 'cancelled' individuals in school curricula.	Lesson I began with Dave modelling his own Research Café presentation around salmon farming. The SSI of fish farms was forwarded and a scientific article explaining the impact fish farms were having on native salmon populations was used a base. Dave then led students in a discussion on the ethical implications of fish farms, highlighting anthropocentric and ecocentric worldviews as a framework for the discussion. The presentation closed with Dave putting forward a personal challenge he would take to address the SSI, including using the OceanWise website to guide his fish purchases. The class then reflected on Dave's presentation for its strengths and weaknesses, before students reengaged with researching their Research Café projects.	Lessons II had students ready their projects for presentation, combing over the social/ethical discussion they were going to lead and researching their personal challenge which might address the SSI presented in the article. Questions forwarded by Hodson (2014) such as: Who are the SSI stakeholders? What constitutes their interest? Whose voices are privileged and marginalized? Were used to further students' thinking. Lesson III and IV were student presentations. A student example included the SSI of deep-sea mining, the ethical dilemma of harming the environment (e.g., deep sea reefs) versus the need to extract materials for renewable energy technology, and the personal challenge of setting up an electronics recycling system at the school.

Appendix G: Lesson Descriptions for Mike's Research Lessons.

Lesson I – Trio of Actions	Lesson II – Carbon Thinking	Lesson III – Sharing Session	Lesson IV – What Now?
Lesson I focused on extending and solidifying central concepts from Module One and Two of the Climate Change Unit on Earth's Systems and Humans as Part of Earth's Systems, respectively. The lesson was organized under a 'trio of actions.' First, students were invited to reflect on their interest in climate change and the impacts it was having on their lives and those they know. Second, books, quotes, and articles that highlighted different climate change lenses were presented. Students were prompted to engage in discussion around what interested them most including some of the perils of climate change, how the scientific community knows those to be true, current mitigation strategies, questions they would pose to stakeholders, and personal actions they were undertaking from a climate-conscious perspective. The class closed with an introduction to the project students would do which described a carbon emission reduction action they could take on. Students were assigned homework to discuss with their families which actions might be most appropriate (the final action).	Lesson II had students share the conversations they had with their families as homework and begin to research three individual or family actions they could take to lower their personal carbon emissions. Project DrawDown and other internet-based resources served as examples. Mike also presented his own action (biking to work) as an option students could take. Deciding on one of the actions, students then had to show mathematically how their emissions would be reduced (i.e., develop a scientific logic model) and were tasked to write a reflective paragraph on 'big picture' message as homework. The paragraph included how they came to choose their action, why they thought it was important, what new learning they encountered when engaging in the research, and how others might perceive that action chosen. Students were given a work period to make a presentation detailing the action they chose and highlighting why it was contributing to reduced carbon emissions.	Lesson III had students share their presentations on which climate change mitigation strategy they forwarded. Potential actions varied widely. Some included the impacts of tree planting along busy urban roads, the carbon saving of driving to all vacation destinations versus flying, and the impacts of eating locally in relation to supply chain emissions. The class closed with the administration of a post-learning survey, covering not only the outcome desired in Module Three, but the entire climate change unit.	The first half of Lesson IV was dedicated to a debrief of student presentations. Discussion flowed freely, following student interest. Foci included why it is so hard for society and individuals to get behind real change and a debate around the relative importance of personal actions versus wide-scale technological solutions in addressing the climate crisis. The class closed with an invitation for students to engage in the 'Hope To' epilogue. Students were invited to sign up for the project, and plans were made to follow the students every two weeks as the enacted what their presentation detailed. Space on Earth Day 2021 was planned for a learning celebration of these actions.

Appendix H: Final Reflective Prompt Document

Questions completed by teachers to structured post-Learning study interview.

Reflective prompts before the final meeting
10 minute or less time-box

Please answer the following prompts (typed, voice memo, etc.). This will start the final meeting and interview process. When sending, please also include the location of the final $30 gift card.

<u>Prompts</u>

Participating in the Learning study made my learning about SRSE [fill in the blank]. Why?

Participating in the LS made my learning about my own pedagogy [fill in the blank]. Why?

Participating in the LS made my learning about the 3 Visions of scientific literacy (conceptual, contextual, critical) [fill in the blank]. Why?

<u>Finally</u>

Is there anything else of note you want to bring up?

Appendix I: Dave's Farming Practices Vignette

In the farming vignette, explained in Individual Support 9, Dave explained how he gave a small lecture to his class on soil "for about four, five minutes, like how darn cool soil is" including how farming techniques, like precision agriculture, can reduce soil damage. From this base, Dave proposed a question to the class to begin a discussion: "If we are a committee in the government, what should we know to mandate that by 2030, all farmers are practising precision agriculture and using the tools required to do so?" (Individual Support 4, 9:10) From there, Dave had his students engage in a lively discussion. Dave explains:

> **Dave:** I just kind of gave them the scientific backing and some context, and, you know, what should we know? What are the pros and cons? The considerations? And it was great. I think that class they were more into the conversation than virtually any class we've had this year. And then we went off on tangents, we were talking about Tesla. Should the government subsidize Tesla? And I'm like, well, they do a little, they take five thousand off. For some reason, if you buy a Nissan Leaf, they take ten thousand dollars. And a student was like, well isn't that interesting? You know, that's a good economic bucket. Or maybe there's some bent government axis, right? A political bucket. Or the owners of Nissan are friends with Canadian politicians or something? So, lots of critical questions, that are so important for these issues later in life, came from it. (Individual Support 9, 10:16)

In this example, Dave highlights the building of conceptual and contextual understanding which he used to position students' as engaged critics of farming practices, and then the nature of government subsidy for electric cars.

Appendix J: Nicole's China Plague Vignette

An experience representative of the individually transformative approach to SRSE came as a vignette Nicole shared related to her research lessons.

> **Nicole:** So one conversation we had, we're just talking about COVID and one student says, oh, like Trump calls it the China Plague. And I was like, awesome -- well that's not awesome -- I mean, we're going to lean into this. I'm going in. We're doing this. So we talked about like, well, you know, what's the impact of him calling it that? Because that's not actually what it is, and how would that make people feel? And one student was like, well, like I read or heard something about a woman being harassed on the bus because she's Asian. And another one was like, oh, I heard about businesses that are run by Chinese people losing money. And so, we like sat on that for a long time. And I was like, so should we call it that? What should we do? And in the conversation the whole time I was like, I'm doing this! It's happening! And this was like a response to like, leaning into areas I normally wouldn't. (Individual Support 3, 32:01)

In this vignette, Nicole highlights how she organically sought to transform students' attitudes and beliefs toward the impacts of disease etymology. Nicole first discussed with her students' the harm science-related terms can have and then supported them in deriving an opinion on what to do next. This practice of facilitating students in taking a stance on select socioscientific issues was a means towards individual transformations shared by all teachers in the Learning study.

Appendix K: Nicole's Gender Disparities in STEM Careers Vignette

Nicole provides an example of her engagement with students about a socioscientific issue she had an interest.

> **Nicole:** But, you know, I look at one student-wide conversation we had this year that just kind of came up about gender and science. And we just like started having a chat. And eventually, everyone wheeled all their chairs, and we were just this like, clump of wheely chairs. We were having this conversation, and this one student, this male student, was like, no, it's not an issue. And then there's some points shared. And he left class being like, I've never thought about this, and I'm wrong. Like, he literally just, it was such a strong 180, where he just never actually had the exposure or the conversation. And I was like, worth it! Like we have literally opened someone's eyes to a whole side that they've never seen. Like, OK, yeah, we're going to we're just gonna pause everything and have this 20-minute conversation, and this is what we'll do right now. And it was like it was just by invitation. So a couple of kids were talking, and I wheeled over just kind of like structured it if nothing else. And the next thing you know, the whole class is there. (Int 2, 39:55)

In this excerpt, Nicole explains a class-wide conversation she structured around gender disparities in science careers. This issue was of interest to her as a female engineer.