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***in education* Volume 31, Number 3, 2026 Autumn [Special Issue]**

Editorial

Kathleen Nolan, *University of Regina*

Welcome to the third and final issue of *in education* for 2026, and to our second Special Issue of the year! In this issue, we are pleased to present a focus on **Socioscientific Issues in Education: Voicing Canadian Perspectives**, guest edited by Latika Raisinghani (University of Winnipeg), Ellen Watson (Brandon University), and Lilian Pozzer (University of Manitoba).

As Editor-in-Chief of *in education*, I have appreciated working with these three dedicated and inspired scholars over the past few months. The four articles, two essays, and two book reviews in this issue bring to life for the reader the significance of socioscientific issues (SSI) in educational contexts, with editors and authors posing key questions about how science educators can embrace teaching and learning through/with/about SSI. As the trio share in their editorial, "identifying and addressing SSI is crucial for cultivating critical scientific literacy, promoting responsible citizenship, and ensuring social and ecological justice."

This special issue is only one of the notable developments marking the 2026 publication year. Over the past months, the journal has undergone significant transitions, including the departures of Valerie Triggs, our former Co-Editor-in-Chief, and Marzieh Mosavarzadeh, our former Managing Editor. Both colleagues made invaluable contributions to the journal, and their absence is already felt. At the same time, this year has also brought new beginnings. We are pleased to welcome Hui Xu, doctoral student at the University of Regina, as the journal's Managing Editor and Luiza Magajewski, from the University of Regina's Research IT Support (RITS) team, as our new Production Manager. We also welcome new faces to our journal's Editorial Board: Associate Editors Katia Hildebrandt, Twyla Salm, and Brittany Tomin and Consulting Editors John Hoben (Memorial University of Newfoundland) and Constantinos Xenofontos (University of Agder, Norway). Thank you all for stepping forward in service to *in education*!

Returning to the special issue herein, I extend my deepest appreciation to guest editors Latika, Ellen and Lilian, and to all the authors whose articles, essays, and book reviews appear in this issue. Their collective work has allowed *in education* the opportunity to showcase vital and thought-provoking scholarship on socioscientific issues currently being voiced by Canadian scholars.

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in education **Volume 31, Number 3, 2026 Autumn (Special Issue)**

Socioscientific Issues in Education: Voicing Canadian Perspectives

Editorial by Guest Editors

Latika Raisinghani, *University of Winnipeg*

Ellen Watson*, Brandon University*

Lilian Pozzer*, University of Manitoba*



Photo Credit: Latika Raisinghani, 2019

The above photo was taken by Latika Raisinghani in Regina on September 16, 2019, as she went for an evening walk. At that time, Latika did not imagine that experiencing nature's beauty through such walks would become a rare event only six months later. On March 11, 2020, the World Health Organization (WHO) formally declared Coronavirus disease 2019 (COVID-19) a pandemic (Cucinotta & Vanelli, 2020). Soon after, classes were suspended and then moved online indefinitely; people were advised to maintain social distancing and to work and study from home. Locked indoors for days, Latika remembers looking at the photo above and feeling that, despite we, as humans, were imprisoned within the boundaries of our homes, nature outside continued to thrive. The science around this novel respiratory disease also evolved as its cause was eventually identified as severe acute respiratory syndrome coronavirus-2, or SARS-CoV-2, but its implications went well beyond health. Economic, political, and social disparities between the Global South and the Global North became more obvious as the race to find a 'cure' intensified. Once vaccines were developed, access to them and the effort of educating people about the benefits of getting vaccinated became prominent issues. Six years later, with the severity of the pandemic having now subsided, many people still live with long COVID, and others still suffer the rare side effects of vaccines. The COVID-19 pandemic is just one example of a socioscientific issue.

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Socioscientific issues (SSI)[1] are complex, wicked, real-world problems that have no easy answers (Frisch et al., 2026). Rooted in scientific concepts, SSI are shaped by sociocultural values along with ethical, environmental, political, economic, and geographical considerations, and the decision-making processes of an informed citizenry. Identifying and addressing SSI is crucial for cultivating critical scientific literacy, promoting responsible citizenship, and ensuring social and ecological justice. As Canadian science educators and guest editors of this special issue, we see a need for this understanding like never before, with scientific thinking (or the lack thereof) at the root of many SSI, such as climate change, vaccinations, genetic engineering, energy and water use, and the social inequities that accompany these issues. Addressing SSI requires crossing disciplinary boundaries, building cross-curricular bridges, and connecting science with social, cultural, environmental, ethical, political, and economic dimensions of specific SSI to promote contextualized learning, informed decision-making, and responsible actions that are socially and ecologically just.

The integration of SSI in science education is a progressive sociocultural movement that shares roots with Science Technology Society and Environment (STSE) (Bencze et al., 2020; Pedretti et al., 2008) and Socially Acute Questions (SAQ) (Simonneaux & Simonneaux, 2012) movements. SSI may focus on raising awareness of and addressing ethical, political, economic, and technological dilemmas that arise from complex STSE interrelationships (Viehmann et al., 2024). The SSI approach extends STSE education by integrating moral and ethical considerations related to social and environmental responsibility into science teaching and learning. In doing so, it promotes scientific literacy by inviting students to critically examine the benefits, limitations, and broader implications of scientific and technological advancements (Zeidler, 2014). Although SSI have been the focus of international scholarship (e.g., Högström et al., 2024), there is a need to create spaces that recognize the contributions of Canadian scholars.

To amplify Canadian voices on SSI education, this special issue of *in education, Socioscientific Issues in Education: Voicing Canadian Perspectives*, highlights 16 Canadian scholars from 12 educational contexts. It offers four research articles, two essays, and two book reviews that explore various SSI in Canadian and broader global contexts to inform social and ecological justice in education. Canadian education has a long history of including SSI in its classrooms (Pedretti & Nazir, 2011), but recent studies (Field et al., 2023; Schatz, 2021) indicate that Canadian curriculum documents, and consequently Canadian education, may benefit from further integration of SSI in teaching and learning science at K-12 levels as well as in teacher education programs. This is particularly evident when considering the rise of misinformation and disinformation related to SSI such as climate change, artificial intelligence (AI), post-pandemic debates around vaccine efficacy and long COVID, and the social and ecological disparities many Indigenous communities in Canada face in accessing clean water and natural resources.

Increasingly, mistrust in science is leading to a rise in diverse partisan polarization across the educational sphere. Hence, the articles and book reviews in this issue address the central question: "How can Canadian science students be prepared for a world where SSI are so strongly

[1] We are aware of the debate over the spelling of "socioscientific" vs. "socio-scientific." Despite the grammatical acceptance of socio-scientific issues, we agree with Zeidler (2014) when he writes "the unassuming hyphen cleaves the social context […] from the science" (p. 699). Hence, we use the term socioscientific to showcase the entanglement of the social and scientific knowledges required to address these issues. However, we have allowed authors in the issue to decide which spelling they prefer.

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polarizing?" The contributions to this issue respond to this central question by inviting readers to think about the following:

1. Whose knowledge and voices are valued and promoted in contemporary educational spaces when discussing SSI?
2. How might students be prepared to critically analyze SSI and become responsible decision makers?
3. What challenges are inherent in implementation and enactment of SSI in teaching at K-12 levels and in teacher education programs? How might we prepare teachers for these challenges?
4. In what ways might holistic education be invited into science classrooms, addressing SSI and cultivating relational connectedness with the human and more-than-human world as informed by the Truth and Reconciliation Commission of Canada's (TRC) Calls to Action (TRC, 2015)?

The first three articles, by **Emily Krushelnycky** and **Xavier Fazio**, **Carol Brown**, and **Norris Erhabor** and **Giuliano Reis** respond to the second and third questions above. Focusing on preparing teachers for SSI integration, Krushelnycky and Fazio highlight the importance of integrating SSI education into Ontario's primary classrooms and offer strategies to support teachers in this work. Brown reflects on her experiences of providing professional development and teaching about misinformation in science education, as well as on a scoping literature review exploring how teachers might be prepared to help students address complex SSI. Based upon a review of selected Canadian literature, Erhabor and Reis argue that teachers face persistent barriers to implementing SSI education in underserved settings in Canada. These authors offer a solution by presenting a cross-cultural case analysis that discusses how a low-cost, community-driven approach to teaching SSI to Nigerian pre-service teachers might inform SSI pedagogy in Canadian rural, francophone, and Indigenous contexts. In response to the second question presented above, **Erin Sperling** and **G. Michael Bowen** analyze Canadian citizen science projects and ask whether participation in these projects promotes an understanding of SSI.

The essays by Deer and Dmello et al. both speak to questions one and four presented above. In his essay, **Frank Deer,** a Mohawk (Kanien'kéha) scholar, contrasts Eurocentric and Onkwehón:we ("the Original Peoples") perspectives on time, inviting science educators to consider the reductionism of the former and the different ways of organizing and interpreting temporal experience. In the essay by **Steffie Dmello**, **Michelle Leonard,** and **Floriane Lévéder,** the authors advocate for a transformative model of science education, in which SSI are enacted through relational, post-human, and Indigenous epistemologies.

Finally, this special issue offers two book reviews. **Puvithira Balasubramaniam** reviews Rola Khishfe's *The Complexities of Socioscientific Issues in Education: Research-Based Insights and Practical Strategies*, a book which addresses the question of how to include SSI in classrooms. **Peiki Loay** reviews *A Sociopolitical Turn in Science Education: Towards Post-Pandemic Worlds*, edited by Canadian scholar Christiano Moura. The contributions in this book focus on the implications of the SSI surrounding the COVID-19 pandemic and post-pandemic changes in science and science education in the Canadian and global contexts.

We are delighted to highlight the voices of Canadian scholars about SSI education in a Canadian journal. This special issue advances scholarly conversations in science education by providing open access to engaging with critical issues pertaining to teaching and learning in

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science education and the broader educational landscape, as envisioned in the scope of *in education* journal. We owe our special thanks to the *in education* Editor-in-Chief, Dr. Kathleen Nolan and to Dr. Valerie Triggs (former Co-Editor-in-Chief), for their guidance and support throughout the preparation of the manuscripts for this special issue. The contextualized contributions of Canadian scholars in this special issue promote research, teaching practice, and theory development to inform a critical scientific literacy that is highly needed to address current social and ecological justice issues. As educators continue their learning of SSI education in a world where social, political, cultural, economic, and ethical tensions prevail, the lingering question remains: How can science educators engage in learning through/with/about SSI without inciting hate speech, ensuring the well-being of individuals and the community, and inviting diverse perspectives with affirmation, solidarity, and critique? We hope you engage with this question as you invite SSI education into the contexts of your own classrooms and broader communities.

References

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

Cucinotta, D., & Vanelli, M. (2020). WHO declares COVID-19 a pandemic. *Acta Bio-Medica: Atenei Parmensis, 91*(1), 157–160. https://doi.org/10.23750/abm.v91i1.9397

Field, E., Spiropoulos, G., Nguyen, A. T., & Grewal, R. K. (2023). Climate change education within Canada's regional curricula: A systematic review of gaps and opportunities. *Canadian Journal of Educational Administration and Policy,* 202, 155–184. https://doi.org/10.7202/1099989ar

Frisch, J. K., Alston, D. M., Feldman, A., Hagevik, R., & Schpakow, M. L. (2026). *Wicked problems in PreK-12 science education: Stories and strategies for confronting complex topics in the science classroom*. Routledge. https://doi.org/10.4324/9781003508793

Högström, P., Gericke, N., Wallin, J., & Bergman, E. (2024). Teaching socioscientific issues: A systematic review. *Science & Education, 34*, 3079–3122. https://doi.org/10.1007/s11191-024-00542-y

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*, 941–960. https://doi.org/10.1007/s11191-006-9060-8

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

Schatz, K. (2021). *Where we stand: The integration of climate change education in Canadian schools*. British Columbia Council for International Cooperation. https://www.bccic.ca/wp-content/uploads/2021/11/FINAL-Climate-Change-Education-in-Canada.pdf

Simonneaux, J., & Simonneaux, L. (2012). Educational configurations for teaching environmental socio-scientific issues within the perspective of sustainability. *Research in Science Education, 42*(1), 75–94. https://doi.org/10.1007/s11165-011-9257-y

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Truth and Reconciliation Commission of Canada. (2015). *Truth and Reconciliation Commission of Canada: Calls to Action*. https://ehprnh2mwo3.exactdn.com/wp-content/uploads/2021/01/Calls_to_Action_English2.pdf

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The use of socioscientific issues in science lessons: A scoping review. *Sustainability, 16*(14), Article 5827. https://doi.org/10.3390/su16145827

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. II, pp. 697–726). Routledge. https://doi.org/10.4324/9780203097267.ch34

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"I Think It Would Just Go Over Their Heads": An Exploration into Teachers' Developmental Views of Elementary Students' Learning about Socioscientific Issues

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Abstract

The children of today are destined to inherit a future marked by insurmountable environmental and societal challenges. To cope, students need to be adequately prepared to become active citizens, equipped with vital knowledge, skills, and motivation to understand and make informed decisions about these challenges. While conversations surrounding the incorporation of socioscientific issues (SSI) in the classroom have been ongoing, a gap remains in understanding how to introduce them at the primary (Grades 1 to 3) level. Guided by the SSI theoretical framework and underpinned by theories of child development, this article explores one element of a larger research study which, in part, assessed how elementary teachers' understanding of child development influenced their SSI teaching practice. The findings examined the qualitative phase of the broader mixed-methods study, in which 10 primary teachers from Ontario, Canada participated in semi-structured interviews. Collectively, these teachers indicated a strong concern that primary-aged students were not capable of learning SSI. Further, they demonstrated a rhetoric-practice cognitive dissonance through inconsistency in their declared beliefs in students' abilities and their teaching practice. Educators, in one sense, were aligned with developmental psychologists and cognitive scientists who recognized the value of complex science-based learning experiences, while in another described elements of a current child's developmental stage as a barrier. Informed by these findings, to support both in- and pre-service teachers in integration of SSI topics, this article offers several developmentally appropriate pedagogies rooted in storytelling, alongside general recommendations for teacher education programs and professional learning.

Keywords: socioscientific issues, child development, elementary science education, storytelling, preservice teachers

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"I Think It Would Just Go Over Their Heads": An Exploration into Teachers' Developmental Views of Elementary Students' Learning about Socioscientific Issues

The children of today are destined to inherit a future marked by insurmountable environmental and societal challenges. It is projected that by 2050, the average global temperature will increase by approximately 1.5°C to 2°C, and, depending on societal efforts, this increment can range from 1.9℃ to over 4℃ by 2100 (Ellis et al., 2024; Lindsey & Dahlman, 2025). Based on these predictions, children born in the year 2020 will experience a significantly higher number of extreme climate events throughout their lives compared to previous generations (Thompson, 2022; United Nations, n.d.). To cope, students need to be adequately prepared to become active citizens, equipped with vital knowledge, skills, and motivation to understand and make informed decisions about environmental and societal challenges.

Conversations surrounding the incorporation of socioscientific issues (SSI) in science education have been ongoing for several decades (Zeidler, 2014), yet a noticeable gap remains in understanding how to introduce complex, science-based issues to primary[1] (Grades 1 to 3) students (Krushelnycky, 2025). Regardless of the cognitive, developmental, and curricular research supporting the integration of SSI, there are limited studies conducted in elementary science classrooms, with even fewer studies sampling primary-aged children (Kahn, 2021). Consequently, these children are excluded from critical conversations and opportunities to grow as actionable citizens, an immeasurably valuable trait given current and future global crises (Fazio, 2023). We argue that young children do not need to wait until adulthood to learn about SSI. They have the right to know about the issues plaguing society and be given the knowledge and tools to navigate these issues (Krushelnycky, 2025).

In this article, we explore one element of a larger research study which, in part, assessed how elementary teachers' understanding of child development influenced their SSI teaching practice. The purpose of our work is to understand the realities of the primary science classroom to better support teachers by suggesting pedagogical strategies to appropriately introduce SSI at this level. In line with this aim, we begin with an exploration of current literature to provide a brief overview of SSI and its evolution within Canadian science education. Then we examine development in relation to cognitive science and learning theory to better realize primary students' capabilities in understanding complex SSI-related topics. We then bridge the two overarching themes of SSI and child development by comparing several studies that specifically describe key development-oriented implications for practice. Building upon these, we describe the larger study's framing as well as the portion of applicable methodology and findings that outline elementary teachers' attitudes towards teaching SSI and perceptions of young students' capabilities. We conclude this article with suggestions for developmentally appropriate[2] pedagogical approaches that are accessible and practical for primary-level science classrooms, as well as outline necessary in-service and pre-service teacher (PST) learning.

[1] In Ontario, Canada, the term primary in education refers to students in Grades 1 to 3 who are between the ages of five and eight. The terms elementary and early elementary will be used interchangeably with primary throughout the article.

[2] The term developmentally appropriate, based in part on the definition provided by the National Association for the Education of Young Children (NAEYC) (n.d.), refers to teaching methods, activities, and environments that promote children's optimal development and learning and match their age, personal strengths, and cultural background.

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The Emergence of Socioscientific Issues in Canadian Science Education

The landscape of science education has undergone substantial change as rapid advancements in science and technology continue to reshape society. Historically, the Canadian science curriculum prioritized the factory model[3] of scientists and engineers for international recognition and to gain a competitive edge in world events (Martinovic & Milner-Bolotin, 2022; Tippett et al., 2019). This was reflected in classrooms across the country, aiming to prepare students for future careers and a society inundated with new technology (Aikenhead, 2005).

The Science Council of Canada's (1984) seminal report, entitled S*cience for Every Student: Educating Canadians for Tomorrow's World*, stated that for Canada to cope with the emerging social changes rooted in specialized technologies, citizens required an education comprised of not only the traditional basics of language and mathematics, but a new contemporary culture of science and technology. This report brought forward four aims to build scientific literacy: 1) to encourage full participation in a technological society, 2) to enable further study in science and technology, 3) to facilitate entry into the world of work, and 4) to promote individual intellectual and moral development, with the concluding consensus of "Science for All" (p. 6) dominating the curricular narrative (Di Giuseppe et al., 2007). In its wake, the Canadianized adoption of programming such as Science, Technology, and Society (STS), later with additional nods to environmental considerations (STSE), and SSI (Pedretti, 2003; Pedretti & Nazir, 2011; Zeidler, 2014) began.

While STS, STSE, and SSI are conceptually related, they are distinct. STSE is an issue-based framework that most tightly aligns with Vision I's idea of 'school science' as it assists students in understanding the nature of, and relationships between, science and technology (Di Guseppe et al., 2007; Roberts & Bybee, 2014). Where STS is limited by its lack of theoretical framing, STSE builds upon it significantly (Aikenhead, 2005; Pedretti, 2003). STSE begins to shift the concept towards Vision II, introducing the advocacy of scientific literacy rooted in ethical, individual, and social responsibility, as well as addressing environmental perspectives, and interweaving multifaceted complexities that envelop a scientific and technologically literate citizen (Aikenhead, 2005; Padamsi, 2017, Pedretti, 2003; Pedretti & Nazir, 2011).

The SSI framework can be aligned with Vision III of scientific literacy (Sjöström, 2024), which involves the deliberate use of scientific topics with ethical-social-political ramifications that necessitate students' participation in various forms of discourse (Zeidler & Sadler, 2023). It contextualizes personally relevant, often controversial, and ill-structured societal issues that inspire scientific, evidence-based reasoning to inform the decision-making process, while orienting curriculum to real-world experiences (Chowdhury et al., 2020; Sjöström, 2024; Zeidler & Sadler, 2023). The SSI framework has both implicit and explicit ethical components that students must experience, which require a degree of moral reasoning. By extension, it helps to accentuate the formation of character, value, and virtue development as long-term pedagogical goals (Zeidler & Sadler, 2023). In this way, SSI goes well beyond what is often expected in 'school science,' as it encourages the formation of functional scientific literacy per the promotion of citizenry (Chowdhury et al., 2020). Examples of SSI topics include climate change, vaccinations, genetic engineering, water fluoridation, and genetically modified organisms (GMOs).

Given the reputation of SSI topics being more intense when compared to traditional pedagogy for science, it is justifiable that educators would choose the considerably *safer*, fact-

[3] The factory model of education reflects the framing of schooling in Canada occurring primarily during the 19th century to refer to the school-to-career pipeline.

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based approach to content (Zeidler & Sadler, 2023). However, the true benefits emerge from this messiness, as learners who engage with SSI have been found to possess greater overall content knowledge, a stronger understanding of the nature of science, and an enhanced development of ethical, moral, and evidence-based reasoning skills (Sadler & Dawson, 2012). This aligns with cognitive science and developmental theory which point to the necessity of young children's engagement with increasingly complex scenarios to improve higher-order thinking among them.

In-Service and Pre-Service Teacher Professional Learning

Kinskey and Zeidler (2020) have noted that while formal preparation is necessary for PSTs to feel confident in teaching SSI, little has been done for in-service elementary teachers who may not have a background in science or may not have taken an undergraduate science curriculum and pedagogy course in their teacher education program (Krushelnycky, 2025).

Furthermore, teachers must be competent in applying different pedagogical approaches across disciplines. SSI is inherently an intersectional framework as the multifaceted problems it explores overlap with social, economic, ethical, political, and scientific factors that require cross-disciplinary thinking (Zeidler & Nichols, 2009). In tandem with Zeidler and Sadler (2023), one method to mitigate developmentally centred learning is to become competent in enacting interdisciplinary curriculum. Thus, to proactively approach SSI and encapsulate its complexity, SSI education must begin during teacher education so that PSTs feel capable of applying several disciplines at differing levels of integration in their future classrooms. Deriving from this, both PSTs and in-service elementary educators must unify their knowledge of SSI, interdisciplinarity, and development theory to execute appropriate pedagogical tools.

Development and SSI During the Formative Years

Even in the 21st century, our understanding of child development is still evolving. As an educator, having an informed understanding of a child's development plays an invaluable role in our awareness of how children learn about SSI and how that knowledge is compartmentalized (Krushelnycky, 2025; Metz, 1997). Throughout history, theories have attempted to organize and make sense of why people are the way they are (Miller, 2022). Notions of childhood and development theory are anchored in the writings of philosophers such as John Locke and Jean Rousseau (Budzyna & Buckley, 2023). Their revolutionary ideas, conceptualizations of integrated curriculum models, and child-centred approach to teaching would eventually emerge and pave the way for modernized approaches (Budzyna & Buckley, 2023; Koops, 2023).

Developmental theorists such as Jean Piaget, a representative of traditional education, and Lev Vygotsky, a figurehead of the social reconstructionists, laid the foundations of how we approach education and underpinned how curriculum is developed (Vadeboncoeur, 1997). Historically, Western education in Canada has been primarily influenced by Piagetian theory (Zhang, 2022), believing that an individual's thought processes change slowly over time across four distinct developmental stages, each progressively becoming more advanced and nuanced than the last. However, in more recent years, schooling has taken a more Vygotskian approach, emphasizing the role of one's social environment, the co-construction of knowledge, and the value of socioemotional elements (Cohen, 2017; Keenan et al., 2016; Scott & Cogburn, 2023). While longstanding theories have shaped the concepts of childhood and development for decades, concerns now arise regarding their relevance to current generations, given that advancements in technology and significant social changes have transformed the developmental landscape (Krushelnycky, 2025; Miller, 2022; Ryan & Grieshaber, 2004). Furthermore, these foundational

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theories inform educators' perspectives when teaching SSI, making their influence invaluable by way of their role in teachers' practice.

Learning and Complex Thinking in SSI

As is in the name, the formative years (up to eight years old) of an individual's life are critical for cognitive, physical, social, and emotional maturation, as well as the most transformative for the development of morality (UNICEF, n.d.). Experiences during this period affect the architecture of the brain, laying the foundation for future learning and behaviours (Center on the Developing Child, n.d.). Countless studies of early cognitive development have highlighted the incredible nature of the mind, labelling it as competent, active, and insightful beginning in infancy (Allen & Kelly, 2015; Ma, 2013).

According to Dehaene (2020), children behave like "budding scientists" (p. 60) from birth, who reason like statisticians and seek logic in the abstract by searching for hidden causes of various phenomena. This innate tendency to question, identify patterns, and construct explanations, reflects the idea that children are capable sense-makers who actively engage with the world around them. These complexities are not limited to tangible manifestations such as object permanence but extend into the realm of morality (Dehaene, 2020). Beginning in early infancy, children begin to recognize the binaries of right and wrong, while continuing to learn moral reasoning through observation of and modelling from perceived influential figures such as parents, guardians, and teachers (Bandura, 1971; Dehaene, 2020; Ma, 2013).

Hence, it becomes especially imperative that young children are provided opportunities to observe, explore, and engage with stimuli that encourage the formation of ethical and moral reasoning skills. This reasoning helps children to recognize perspectives different from their own, think critically about the concepts of right and wrong, and use these to develop a sense of empathy (Killen & Dahl, 2021; LoBue et al., 2011). As children's empathy and cognition mature, moral development progresses, highlighting the importance of educational programming like SSI that cultivates character growth through ethical dilemmas involving several forms of dialogue. Exposure to these conundrums creates cognitive conflict that necessitates higher order thinking required for development (Kohlberg, 1981; Yilmaz et al., 2019). To fully understand how children learn and grow in conjunction with how they interact with SSI, it is crucial to look beyond the conventional intersection between genetics and the environment, and towards a perspective that incorporates the many sociocultural, biological, and psychological systems that are encountered by children as they move through life (Seifert, 2012).

SSI in the Primary Science Classroom

Debate remains ongoing regarding whether SSI education is possible or desirable in elementary science classrooms, with those citing the need to improve scientific literacy, and those opposed describing knowledge constraints and developmentally inappropriate conversation (Lewis & Leach, 2006; Roberts & Bybee, 2014). For example, while studying environmental ethics, Sobel (2008) observed that young children can easily become overwhelmed by environmental issues. As per Sobel, discussions surrounding SSI should begin at fourth grade or later, as discussing these earlier causes significant emotional distress and ecophobia. Similar findings were reported by Kahn (2021), who notes that the students of Grades 1 and 2 struggled to navigate between real and fake situations, struggled to manoeuvre between emotional and rational thought during scientific argumentation, and experienced difficulty in regulating emotions.

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The findings across these studies are not uncommon, with the primary pitfall experienced being premature abstraction while discussing SSI. The concept of abstraction in cognitive science refers to the fundamental process of distilling the complexities of sensory experiences, relationships, and nuances of life into generalizable, symbol-like mental concepts without them being immediately present or tangible (Sheposh, 2022; Shivhare & Kumar, 2016; Suh, 2019). The ability to think in this manner varies at different levels of learning. Both cognitive development and ability evolve gradually from infancy to adolescence (Chaparro-Moreno et al., 2023; Demetriou, 2020; Gleason & White, 2023). Premature abstraction, then, refers to the attempt to accelerate, teach, or force a child to process macro-level concepts beyond their current cognitive abilities (Dumontheil, 2014; Sobel, 2008; Stanborough, 2026). While the ability for a child to think in this way may appear advanced, it can lead to excessive worrying and catastrophizing as they attempt to navigate adult-level concepts without the emotional maturity to cope (Sobel, 2008; Stanborough, 2026). Regarding SSI education, Sobel (2008) specifically cited concerns of stripping the wonder and whimsy from learning.

Similar research situating environmental issues from children's perspectives has revealed that their concerns were often expressed intensely through sadness, anger, fear, and an overwhelming pessimism towards the future, which often clouded their abilities to fully engage with the SSI (Pihkala, 2024; Strife, 2012). Heightening these already intense emotions, before even entering the classroom, children are often exposed to forms of media (e.g., television, movies, social media, etc.) that tend to frame SSI (most notably climate change and global warming) as apocalyptic via a fear appeal tactic (McKnight, 2010; Strife, 2012). Rather than promoting pro-environmental behaviours, such approaches cause feelings of frustration and powerlessness (Sobel, 2008; Strife, 2012). However, in opposition to Sobel's call for complete avoidance, Kahn (2021) amplifies the necessity of implementing the SSI framework during early elementary so students could exercise their moral reasoning skills, practice building evidence-based arguments, and better comprehend the nature of science.

It is also worth noticing that Gormley et al. (2019) and Spiteri (2021) mention that young children who engaged with SSI topics did not exhibit ecophobia, but demonstrated positive attitudes towards environmental preservation and conservation, showed enthusiasm for learning others' perspectives while sharing their own, and made connections to their community through action. Across the empirical studies, broad SSI topics such as pollution, healthy eating, forensics, and native wildlife were localized and presented to elementary students. These real-life issues addressed held significance to students as they were current in their community and personal interests, while being aligned with regional curriculum expectations. Additionally, both Gormley et al. (2019) and Spiteri (2021) suggest that discussion of the SSI topics should be done in a manner that fosters an appreciation for the environment, encourages citizenry, and promotes actionable change, all through a hope-oriented lens. Alongside this, to quell concerns of ecophobia and appropriateness, pedagogical adjustments should be made to adapt to primary students' current development including age, experiences, and interests (Gormley et al., 2019; Spiteri, 2021).

Theoretical Framing of the Research Study

The larger empirical study that informs this article was guided using the SSI theoretical framework, which holds dual purposes in science education: its utility in addressing SSI in the context of the psychological, social, and emotional maturation of learners, and its flexibility to the sensitive nature of multiple perspectives of research pertaining to scientific literacy (Zeidler, 2014; Zeidler & Sadler, 2023). Conceptually, the SSI theoretical framework was designed to utilize the science

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curriculum as a vehicle to foster individual moral sense and discernment, character development, and social responsibility. Additionally, this study was informed by several theories of child development of cognition, socioemotional skills, morality, and learning. All domains and interpretations were treated equally, with no single theoretical approach considered over another. The following research questions guided the larger study and inform this article:

1. How do teachers' assumptions of primary students' ability to engage with socioscientific issues impact their implementation?
2. How might we support primary teachers to navigate the unique challenges of presenting SSI to young students?

The first question delineates the scope of the initial study, the findings of which are presented in the subsequent section. The latter question emerges as a logical extension of these conclusions and examines the prospective approaches of SSI within primary science classrooms.

Methodology

The larger study was approached pragmatically, utilizing an exploratory sequential mixed methods quantitative-qualitative design to address the multifaceted nature of SSI and child development. Quantitative data collection began in October 2024 until February 2025 via an online survey (N=41), directly followed by voluntary, qualitative, individual, virtual semi-structured interviews (n=10) which took place from February 2025 to March 2025 (Krushelnycky, 2025). This article focuses on the findings based on the qualitative interviews.

The participating teachers were a combination of eight generalist and two itinerant primary-level science teachers from a school district in Ontario, Canada. Generalist primary teachers were described as individuals who are not specified science teachers, while primary level science teachers were defined as those who specifically teach science on rotation as an itinerant. Their classroom experience ranges from Long Term Occasional (LTO) to over 30 years' permanent full-time teaching. Each interview was audio-recorded and transcribed through Microsoft Teams™ AI-generated software. Transcripts were reviewed in tandem with recorded audio to ensure accuracy. Scripts were anonymized and returned to respective interviewees to conduct a member check.

Once the finalized transcripts were returned, an inductive thematic analysis was employed to synthesize common themes and explore the distinct experiences, perspectives, and insights shared by the teachers. A manual coding process, beginning with open coding, was used to thoroughly capture participants' experiences (Bingham, 2023). This was followed by axial coding to re-examine and identify relationships and patterns amongst surfacing concepts (Simmons, 2017). Scripts were then re-reviewed, and emerging themes were refined through clear definitions. Direct quotes that most aligned with the conceived codes and definitions were identified and culled. A finalized subset of common themes was identified, and conclusions were drawn in relation to the study's research questions.

For this article, responses to questions that pertained to teachers' attitudes towards and understanding of SSI and child development are explored in-depth to highlight the intersection of these in science education. When directly referring to a teacher's response, a pseudonym is used, and the grade they were teaching at the time of data collection is indicated.

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Findings and Discussion

Overwhelmingly, the teachers in our study were cautious in their perceptions of students' learning capabilities (e.g., cognitive abilities, emotional readiness, maturation, etc.) and continuously connected this perception to students' developmental stages. From this, two systematic cognitive dispositions emerged: a bias based on the perception that children's stage of development is a deficit to their potential to learn about SSI and a cognitive dissonance centred on the attitudes and execution of educators teaching SSI.

Teachers' Concerns Around Children's Developmental Stage as a Hurdle for SSI Education

A frequent concern that emerged from participants was the perception of young students. Teachers reported that children's developmental stages in the primary years limit their ability to learn about complex science-related topics. Participants suggested that primary students were incapable of meaningfully engaging with SSI topics that require higher order thinking skills, life experience, and a certain level of cognition and maturation that is achieved only in adolescence. Moreover, teachers commented on the developmental appropriateness, which is described as the expectations, environments, and teaching methods that best align with a child's current age, individual abilities, and cultural background (NAEYC, n.d.; Schon, 2022) of SSI. Many of these concerns were rooted in the fear of scaring students or causing distress. Teachers further perceived students as lacking the cognitive capacity necessary to process SSI without experiencing cognitive overload. Therefore, children's developmental stage was perceived by these participating teachers as a barrier to potential learning of complex SSI related concepts that involve ethical and moral dimensions, recognition of consequences, identifying cause and effect, recognizing and valuing differing perspectives, risk of ecophobia, etc.

The participating teachers also commented on students' perceived shortcomings such as egocentrism, lack of maturity, inability to recognize nuances of complex situations, and emotional dysregulation, identifying these as constraints that would only allow surface-level understandings of any SSI topics presented. For instance, Ms. Miller who was involved in teaching science as an itinerant teacher for over 20 years, expressed their perspective on primary students' ability for abstraction: "Children as a rule are very egocentric … if it's not in their immediate vicinity, they don't have the cognitive ability to see the bigger picture." In the same vein, Ms. Jones, a generalist Grade 2 teacher, had concerns as to whether or not it would be worth introducing SSI in their classroom. They noted that young students would not be able to form meaningful connections between the science concepts and the world around them: "I don't think they [the Grade 2 students] get the impact locally, but I do think they have a general knowledge and understanding about what it means, but the impact, I think that's still far away." Similarly, Ms. Walker, who was involved in teaching science across Grades 1 to 3 for over 20 years, commented, "I think they [the students] are still too little. I mean you could [teach SSI topics], but I don't think they're going to fully understand."

Like other participants, Ms. Summers, a generalist Grade 3 teacher, placed significant weight on the maturity of young students as to whether teaching SSI is worth attempting, stating, "I feel like [for teaching SSI], a junior grade level [Grades 4 to 6] would be appropriate. However, depending on the maturity level of your grade threes [the students of Grade 3], because they're at the end of primary …, it all depends on the maturity level." Other teachers were more direct in expressing their concern about younger students' cognitive abilities. For example, when asked

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about introducing SSI to primary students, Ms. Rain, a generalist LTO currently teaching in a Grade 2 classroom, claimed, "I think it [the teaching of SSI] would just go over their heads." Ms. Rain's statement summarizes the common consensus among teachers' who shared similar sentiments when parsing rationalizations for not teaching SSI topics in their primary classrooms. Teachers also expressed discomfort around teaching SSI as evident in the following interview excerpt from Ms. Smith, a generalist LTO teaching across the primary division. Ms. Smith commented:

> My first instinct is to like, oh my goodness, I have to hide it [the SSI topics] from them … I don't want to expose them to something scary and traumatic. But I've started to realize it's actually ok to have these conversations about it. ... Children are naturally curious; they [students] ask questions all the time. (Ms. Smith, Individual Interview, March 2025)

Overall, teachers considered primary students' developmental maturity, cognition, and experience as significant barriers to meaningfully engage with SSI, influencing their decisions to introduce these complex issues in the classroom.

Cognitive Dissonance: Attitude vs. Execution

Across this study's findings, there was a sense of hesitancy and ambiguity among educators about teaching SSI in primary/elementary grades with the phrase 'it depends' preluding most of their responses. Overarchingly, this phrase was used to paint some students as more capable (in terms of cognition, maturation, etc.) than others, which in turn, generalized groups of children in their classroom. Paradoxically, several teachers who held these beliefs also praised primary children's potential as per their developmental stage. Most teachers expressed this disconnect implicitly, referencing phrases such as children being "like sponges" (Krushelnycky, 2025, p. 99), before going on to list several development-centred challenges as to why it was not possible or desirable to introduce SSI at this grade level. For example, Ms. Carter began by commending young children's perspectives and abilities to engage abstractly with complex topics at the Grade 2 level as evident in the following interview excerpt:

> Children are incredibly bright … they can pay attention to far more things than I think we realize, and I just find, over my years of teaching, I just find that children see things in a different light than maybe even we're thinking they do. (Ms. Carter, Individual Interview, January 2025)

Yet, they quickly added that certain elements of SSI should be avoided due to their complexity, stating:

> If you're talking about things like a real-world problem, like recycling, I think you can start that as early as JK [Junior Kindergarten]. I think if you're starting with something a little more complicated or controversial, I would say wait until probably the junior grades [Grades 4 to 6]. (Ms. Carter, Individual Interview, January 2025)

This mismatch between participating teachers' beliefs and actions reflects cognitive dissonance, a psychological phenomenon in which an individual simultaneously holds two contradicting beliefs that cause discomfort (Harmon-Jones & Mills, 2019; Korteling & Toet, 2020). These primary teachers, in one sense, aligned with developmental psychologists and cognitive scientists in terms of young children's exceptional learning potential and the value of critical experiences, such as those available through SSI (Gormley et al., 2019; Kahn, 2021). On the other hand, they described elements of a current child's developmental stage as a barrier to

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introducing SSI. Research suggests that when an educator experiences discomfort or hesitation in their practice, developmental knowledge prevails (French & Woodring, 2012). This should allude to the idea that teachers would become more inclined to attempt or appropriately adjust SSI topics to suit primary students' needs because they have the knowledge of foundational child development theory to do so. However, as evident in the findings of this study, even with this awareness, teachers remain wary of teaching SSI in their primary classrooms.

Teachers' Perceptions of Primary Students

The perspectives expressed by primary teachers closely align with Kahn's (2021) findings, as they also identified that young children's science learning abilities are frequently underestimated by the teachers due to deficit-oriented approaches about children's cognitive abilities and assumptions stemming from limited understandings of development theory. While we can only speculate on the exact turning point of how teachers' beliefs about children's developmental stage and concerns around the ability to learn SSI came to be, anecdotal evidence provided by the teachers of this study, holds merit. Alongside well-known challenges of time, lack of Ministry of Education-appointed resources, and limited administrative support (Presley et al., 2013), these teachers described a "generational shift" (Krushelnycky, 2025, p. 59) in terms of how students learn, behave, and socialize with one another. The predominant message reflected in their interviews indicated that the children today cannot do what the children of past decades could. For example, when comparing primary students throughout their years of teaching, Ms. Williams, a generalist Grade 3 teacher with over 20 years of experience, stated: "Students that I had 10 years ago, yes [they could understand SSI]. Students today, again, it depends on the topic … I think that kids today … they are not engaged in what's going on in the world around them." This illustrates that SSI was once possible at the primary level, but within the current classroom climate, it does not feel feasible.

Hence, based on the findings of this study and supporting literature (Barr et al., 2024; Krushelnycky, 2025; Miller, 2022), it can be theorized that the hesitation of teachers to integrate SSI may stem in part from misunderstanding of child development in theory and practice. Children, as noted, are being raised under incredibly different circumstances in comparison to those observed when foundational theories were emerging. Modern factors, including increased screen time beginning in infancy (McArthur et al., 2022; Muppalla et al., 2023; Ponti et al., 2022), sedentary lifestyles (Prince et al., 2020), limited socialization caused by the COVID-19 pandemic lockdowns (Larivière-Bastien et al., 2022), and contemporary parenting practices (Masamba, 2024; Sanvictores & Mendez, 2022) could not have been originally accounted for in some of these foundational developmental theories, possibly resulting in a disconnect between teachers' understanding of children's potential per developmental and cognitive science. To this end, it can be theorized that teachers' understanding of child development may not be reflective of current realities of children and their learning. As such, reliance on classical developmental theories may be hindering how teachers perceive young students and their abilities to engage in SSI (Cantor et al., 2019, Krushelnycky, 2025). Although SSI are inherently complex, young children possess incipient reasoning, empathy, evidence-based explanations, and sense making that can be intentionally cultivated through developmentally appropriate pedagogies (Krushelnycky, 2025; McCrory & Reiss, 2023). SSI should not be positioned as cognitively unavailable for primary learners; rather, when carefully scaffolded, they may constitute a powerful teaching approach through which children can exercise and further develop these emerging capabilities.

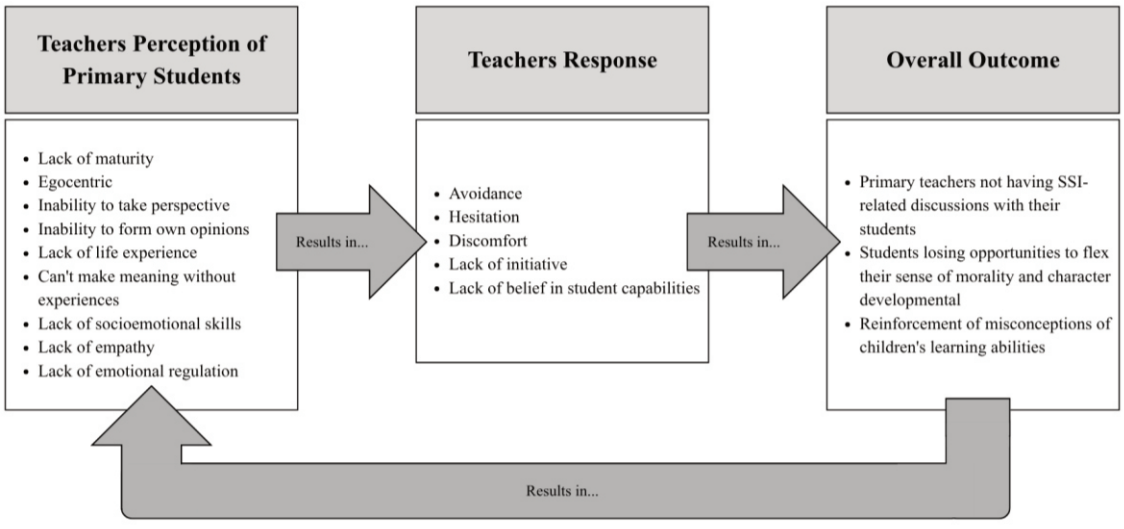
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Based on the findings of this study, we suggest that consistent phrasing from teachers in terms of children lacking cognition and socioemotional skills not only diminishes their potential but also reinforces the faulty narrative that children are incapable of meaningfully learning about complex SSI topics (see Figure 1). To quell these uncomfortable feelings, teachers avoid introducing SSI topics to their students and are far less likely to take the initiative of integrating such topics into their practice. These decisions are rationalized per the initial assumptions of primary students' developmental state. Consequently, the outcome of these teacher behaviours is crucial as it results in the absence of teaching and learning opportunities of SSI topics during children's formative years. Eventually, should this cycle continue as children progress through the primary grades, this will lead to the risk of decreased motivation and interest in critical science topics, lowered scientific literacy, and potentially create further societal challenges in future as also evident in the previous studies (Allen & Kelly, 2015; Bastani, 2016; Zeidler & Sadler, 2023). It is important to note that these findings do not intend to blame educators for holding particular beliefs about children and their developmental stages. Instead, they highlight that the issue of introducing SSI at the primary level is incredibly complex. Because an individual teacher's content knowledge about specific SSI topics, comfortability, emotions, and personal beliefs of what is 'best' for their students, influences their decisions as to whether teaching and learning of SSI should be addressed at this age-level. Alongside these, the multifaceted demands that are placed on teachers and the complexities of the classrooms also play a significant role in the decision-making process.

In the next section, we describe some developmentally appropriate pedagogical strategies for introducing SSI in primary science classrooms that may help interrupt this cycle.

Figure 1

Model of How Primary Teacher Perceptions Develop



Recommendations for SSI-based Pedagogical Strategies with Young Children

To support in-service primary teachers' and PSTs' integration of SSI topics into their science teaching practice, an understanding of developmentally appropriate pedagogical approaches is needed. At present, literature describing the incorporation of SSI topics in primary science classrooms is relatively scarce, with most studies sampling university, secondary, and upper

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elementary (Grades 4 to 8) students. To compensate, we draw from early childhood development research while interweaving familiar, accessible pedagogy that may allow generalist primary teachers to confidently explore SSI with a child-centred approach. In the following section we discuss storytelling and its various forms as potential pedagogical strategies for teaching SSI to young children.

Storytelling

Despite being one of the most fundamental tools available, storytelling is often overlooked in science education (Andrade, 2025). The concept of storytelling and orality exists universally across cultures as our most natural and familiar way of compartmentalizing experiences (Bruner, 1996). In fact, it is the way in which most human knowledge is constructed within the context of personal stories and relevance (Bowman, 2018; Landrum et al., 2019). Storytelling in a teaching capacity serves several purposes, including fostering interest, providing structure for content, sharing information through an accessible medium, and helping in creating a more personal connection between knowledge and learner (Green, 2004; Landrum et al., 2019). As a pedagogical tool, its effectiveness emerges from its concreteness, specificity, and narrative organization (Walan & Enochsson, 2019). From a cognitive science standpoint, storytelling is considered psychologically privileged in terms of memorability. At its core, the human brain reacts to what is happening in a story as though it were a genuine experience (Landrum et al., 2019). This is because it has evolved to process lived experiences sequentially in scripts akin to narratives (Copeland et al., 2015). This intersubjectivity allows learners to empathize with characters and fill-in undisclosed gaps regarding their perspectives via active comprehension (Landrum et al., 2019).

Many of the benefits of storytelling align with the work of Kieran Egan, whose theory of imaginative education proposed a five-stage model that described children's development through successive, increasingly sophisticated cognitive tools, the most applicable at this time being mythic (Krushelnycky & Karrow, 2024; Egan et al., 2016; Judson et al, 2021). Although there is no defined age per stage, mythic understanding tends to develop during early childhood, when children begin to categorize the world through binary opposites (e.g., good vs. evil, love vs. hate, sustainability vs. greed, bravery vs. cowardice, etc.), clear beginnings, middles, and ends as they parse through subtleties and nuances of knowledge (Egan, 1986). Alongside this, Egan (2005) proposed a reversal of what is referred to as ad hoc principles, the basis of which stems from the assertion that education relies too heavily on logic and ignores the natural whimsy of a child's mind. Instead, Egan recommended working from the abstract to the concrete, allowing children to explore complex ideas through imaginative means. Science as a discipline already presents young children with countless abstract concepts that can be difficult to fully grasp, with SSI going beyond general content knowledge and necessitating additional higher order processing skills. Through storytelling, these abstract ideas are woven into concrete ones by anchoring them into familiar experiences that children can relate and feel connected to (Hadzigeorgiou, 2016). The narrative structure also provides clear sequencing of cause-and-effect relationships, helping children to visualize abstract aspects of SSI and of how their decisions and actions can and will impact the natural world around them. When combined with intentional fostering of environmental empathy (McKnight, 2010), storytelling offers a cognitively and developmentally favourable strategy that supports simplification of difficult topics and makes them palatable for young children.

As mentioned previously, the art of storytelling comes in many forms, with the medium in which it is delivered shaping how the message is received, interpreted, and understood by the audience (McLuhan, 1964; Rowcliffe, 2004). The remainder of this section will examine a range

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of storytelling approaches and explore their potential to effectively introduce SSI to primary students.

Picturebooks

Picturebooks[4] may appear simplistic on their surface, but they are a complex weaving of multimodal elements that rely on the interplay between words and images, allowing children to process information both verbally and visually (Crawford et al., 2024; Larragueta & Ceballos-Viro, 2018). Typically, both aspects are crafted purposefully with deliberate, meaningful aesthetics, intended to complement one another. Colour and imagery, for example, are meant to elicit emotional reactions, while the words offer aids in engaging the reader through rhythm, sound, and descriptive language, often using child-directed speech, although they appeal to all ages (Ciecierski et al., 2017; Crawford et al., 2024; Montag et al., 2015).

As a pedagogical tool, picturebooks have been shown to hold incredible power regarding cognitive and socioemotional development (Crawford et al., 2024; Saçkes et al., 2009). Broadly speaking, students' language acquisition and vocabulary improve, critical thinking and comprehension skills strengthen, creativity is enhanced, and empathy is fostered through picturebooks (Niland, 2023; Stewart & Koopmans, 2025). In terms of science education, picturebooks play an invaluable role by presenting content knowledge that is perceived as abstract to young learners and making it concrete while improving both general literacy skills and scientific literacy as well as cultivating scientific inquiry (Fazio & Gallagher, 2019; Saçkes et al., 2009; Sohn et al., 2018).

Using images as cognitive supports, children can bridge seemingly out-of-reach concepts (e.g., climate change, pollution) by presenting such ideas through familiar, affectively stimulating narratives via the combination of visuals and text to enhance understanding (Spielger, 2020). This is especially imperative when addressing SSI topics, as concerns surrounding cognition and complexity can be mitigated through selecting a resource to support learning. Picturebooks have been recorded to be exceptionally effective for character education by facilitating the transfer of core values, with some guidance from educators (Breitfeld et al., 2021; Parker & Ackerman, 2007; Turan & Ulutas, 2016). In their review of the literature, Strouse et al. (2018) found that primary-aged children may struggle with identifying moral messages and often describe superficial characteristics over deeper themes. To accommodate this, the role of the teacher is to facilitate student learning through read-aloud techniques that scaffold learning using deliberate pauses to evoke thinking, asking intentional questions at points of contention to encourage empathic perspective-taking, and clarifying ethical and moral conundrums present so that children may explore them more meaningfully.

Cartoons and Comics

Incorporating cartoons and comics as pedagogical tools first emerged in the 1990s and has since become integral to the landscape of elementary education (McCrory & Reiss, 2023). Both instruments, although separate entities, serve as innovative methods of visual storytelling (be it digitally animated or graphics on paper) and as a medium to simplify complex topics, explore social commentaries, and engage affective domains to aid in meaningful learning (Kumar & Kumar, 2024). With their vibrant visuals and narrative structures, cartoonists not only have the

[4] The spelling of *picturebooks* as a single word signifies the inseparable relationship between words and pictures per research on literacy and storytelling (Crawford et al., 2024).

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ability to shape the experiences of the reader, but the work itself has the power to stimulate cognitive processes (e.g., vocabulary and language acquisition), facilitate information retention, and promote a deeper understanding of complex topics in science (Ozdemir, 2022).

As with picturebooks, comics and cartoons translate complex scientific topics into accessible, developmentally approachable visual narratives. Their multimodal structure supports primary students' SSI comprehension by providing concrete, stimulating representations of seemingly abstract concepts (e.g., the impact of climate change, the necessity of sustainability and conservation, and GMOs). Through the story form, comics and cartoons present a range of viewpoints about science ideas in situations using characters that students can interpret the actions (or lack thereof) and identify consequences or consider alternative outcomes, providing opportunities to improve evidence-based reasoning, promote dialogue, develop scientific understanding and achieve higher quality argumentation skills (Abrori et al., 2026; McCrory & Reiss, 2023).

Puppeteering

Puppetry is a cross-cultural ancient form of artistic expression that is a variation of storytelling and human theatrical productions (McCrory & Reiss, 2023; Speaight, 2023). While there are several different types of puppets (e.g., hand, marionettes, rod, etc.) for varying purposes, a puppet constitutes a moveable doll, whose emotions, thoughts, and (potential) vocalizations are conducted by a puppeteer (Kröger & Nupponen, 2019).

Current media has popularized puppets in children's programming, such as Sesame Street™ and the Muppets™, to not only provide entertainment, but support cognitive, socioemotional, and physical development (Hensley, 2019). Sesame Street™ particularly has been known to tackle complex conversations, including racism, homelessness, grief, trauma, and significant family changes. Additionally, puppets are frequently used as a tool in therapies with young children to help them explore difficult emotions and concerns in non-threatening ways so that they may project their feelings onto a character and process troubling experiences indirectly (Hartwig, 2021).

In formal primary education, puppets have long been successfully used in the dramatic arts and literacy to assist young students in developing academic skills (e.g., communication, language, comprehension), enhancing various cognitive functions (e.g., memory, concentration), and understanding of complex topics (McCrory & Reiss, 2023). Science education is no exception. As puppets function as intermediaries between teachers and students, educators can introduce more controversial, morally loaded topics in a less intimidating manner (Råde, 2021). This form of distancing enables children to experience difficult emotions (e.g., ecophobia, helplessness) that may arise when learning about seemingly bleak issues by humanizing the puppet as a separate entity from themselves (Lillard, 2022). Through thoughtful narrative scripting that appropriately integrates science concepts, educators can use puppets to model various elements of SSI, including argumentation, ethical and moral decision making, perspective taking, and how to draw interpretations using evidence. When students themselves manipulate puppets, they shift their initial recall of science content to one where they are using their knowledge to reason about the issue they have learned with a higher degree of thought, as well as take on the perspective of the embodied puppet who is enduring the SSI from an alternate lens.

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Drama and Role-Playing

Storytelling through forms of theatrics has existed for centuries and involves students in the transmission of both individual and collaborative stories, often embedding metanarratives (whether explicitly or implicitly) while exploring an overarching topic (Verriour, 1990). During childhood, forms of imaginative and dramatic play are incredibly common, beginning as early as 18 months old, increasing with complexity and structure as they mature (Keough, 2024). As children progress, they begin to use this medium to formulate storylines and take on 'roles' as they play. When engaging in these roles, children exhibit the personality, behaviours, and perspectives of the character they embody, often reacting in the ways in which the character would, based on their understanding of the persona and situation. Focusing on primary-level students, drama strategies can be mutually directional forms of play and exist on a spectrum of unstructured to structured, pending educator intent (Ambrosio, 2023).

In primary science, types of dramatic play, such as sociodramatic play, have been shown to serve as a valuable tool for learning about anxiety-inducing issues as children are allowed to grapple with their fears safely (Ambrosio, 2023; Ungvarsky, 2025). This is especially helpful for teachers to quell their concerns about young students developing ecophobia when introducing SSI. Younger students feel comfortable expressing their ideas via a character in a role and for the teacher or peers to question them, helping students develop their thinking about what is ethical in science and why (Peleg et al., 2018). A significant advantage of drama is the element of role play. Role-playing allows students to embody multiple, perhaps conflicting perspectives, which fosters empathy and enhances argumentation skills, through participating in forms of dialogue (McCrory, 2014; McCrory & Reiss, 2023). Through role-play, educators can also facilitate modelling of different moral behaviours and actions via scenarios that encourage students to think critically about choices made by the 'characters' and make connections to their own reactions during similar experiences.

Guidelines for Integrating Storytelling and Implementing SSI in Elementary Science Classrooms

Many primary-level science resources available offer surface-level exploration into standard science concepts, following the traditionally dominant Vision I standard of school science. To move beyond this, two priorities arise: the first being the need for developmentally appropriate materials that explicitly discuss SSI topics, and the second concerning educators' understanding of how to utilize available resources to introduce these concepts effectively. As practical SSI materials for primary students remain scarce, it is important to support teachers' general dissemination of content using what is currently accessible. Figure 2 presents detailed guidelines of SSI implementation as a flow chart.

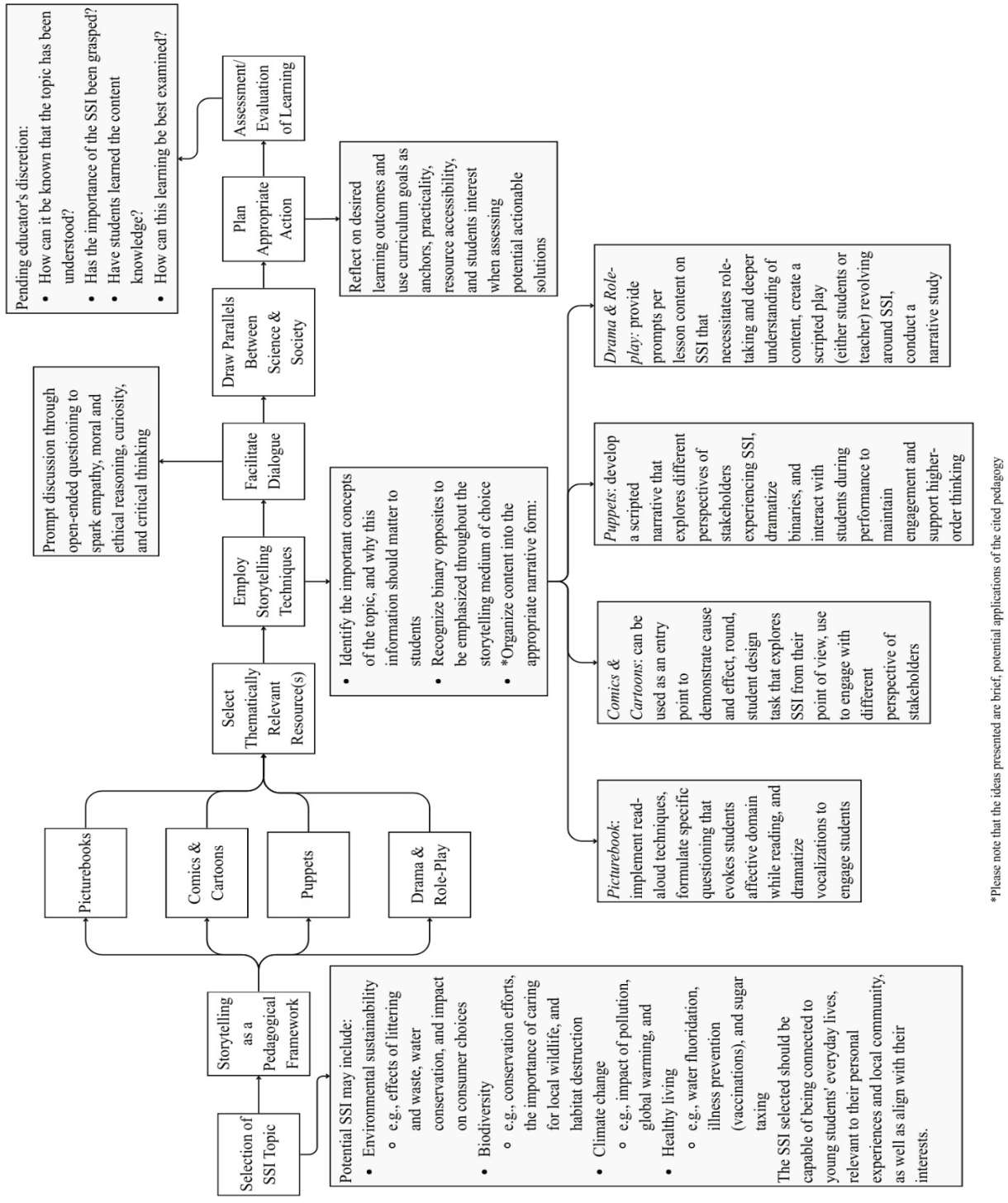
To summarize, the first step is selecting an SSI topic that can be approached meaningfully by the primary students. As with other aspects of curriculum, it is important to interweave an SSI topic that is both relevant and interesting that will spark initial engagement, while also offering opportunities to develop scientific literacy, explore differing perspectives, create opportunities for students to share their thoughts, and work towards actionable change. Additionally, the SSI topic chosen should be age appropriate and aligned with curriculum goals and expectations. Following this, the medium for how the narrative is to be presented is selected based on teacher and student preference, theatrical needs, creative constraints, and the intentionality of the desired message. The

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remainder of the steps are inspired in part by Egan's (1986) story form as well as general lesson preparation. SSI, when paired with a developmentally appropriate pedagogy, like storytelling, can make complex topics, accessible while aligning with primary students' current capabilities.

Figure 2

Implementing SSI Through Storytelling



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Conclusion and Significance

SSI are fundamentally complex, fraught with ethical conundrums and social considerations (Zeidler & Sadler, 2023), and the idea of introducing them at the primary level can feel unviable. The thought patterns displayed by the participating teachers in this study reflect a greater issue of cyclical hesitation and avoidance of SSI teaching based on teachers' assumption of children's capabilities. However, there is still hope for change.

Science education during early elementary is not only crucial to several aspects of children's cognitive and socioemotional maturation, but also to foster an interest in critical science topics (Saçkes et al., 2009). The value of science education as a force for citizenry is invaluable in the way of driving change. Should SSI continue to be circumvented, the potential for harm only increases as children move through their lives, incapable of understanding the issues they will confront. For change to occur, teachers must first acquire a thorough understanding of cognitive science as it relates to current learning and development during formative years. Overreliance on foundational developmental theories without factoring contemporary societal factors may preclude judgment of children's capacity to effectively and meaningfully learn about complex SSI. This necessitates teachers' understanding of the conditions shaping students learning and adapting their practice accordingly. Comparably, generalist primary PSTs may be unfamiliar with the concept of SSI. As such, exposure during science methods courses and supplemental professional learning opportunities that introduce developmentally responsive pedagogy, such as storytelling, and how to integrate SSI topics into their practice are critical to inform PSTs' understandings of teaching SSI to primary students.

Primary students are far more capable than perceived and withholding the reality of their future will only result in ignorance and apathy towards the world around them. Through the careful planning, primary teachers can begin scaffolding complex SSI and encourage young students to explore their potential as contributing citizens in a safe and nurturing environment.

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References

Abrori, F. M., Lavicza, Z., & Cahyono, A. N. (2026). Socioscientific issues comics: A scoping literature review. *Journal of Graphic Novels and Comics, 17*(3), 595–614. https://doi.org/10.1080/21504857.2024.2447311

Aikenhead, G. S. (2005). Research into STS science education. *Educación Química, 16*(3), 384–397. https://doi.org/10.22201/fq.18708404e.2005.3.66101

Allen, L., & Kelly, B. B. (2015). Committee on the science of children birth to age 8: Deepening and broadening the foundation for success. In Board on Children, Youth, And Families, Institute of Medicine, & National Research Council (Eds.), *Transforming the workforce for children birth through age 8: A unifying foundation*. National Academies Press. https://www.nationalacademies.org/read/19401/chapter

Ambrosio, L. (2023). *The impact of dramatic play in early childhood education*. Penn Foster. https://bento.pbs.org/prod/filer_public/pbsnc-redesign-phase-1/education/child-care-101/importance-of-play/14c2549650_Dramatic_Play.pdf?utm_source=(direct)&utm_medium=(none)

Andrade, B. B. (2025). The art of storytelling in science: A personal journey. *Journal of Medical Education and Curricular Development*, *12 (2025)*, 1–3. https://doi.org/10.1177/23821205251318188

Bandura, A. (1971). *Social learning theory*. General Learning Press. http://www.asecib.ase.ro/mps/Bandura_SocialLearningTheory.pdf

Barr, R., Kirkorian, H., Coyne, S., & Radesky, J. (2024). *Early childhood and digital media*. Cambridge University Press. https://doi.org/10.1017/9781108885751

Bastani, R. (2016). Enhancing children's understanding of complex systems: A study of the design considerations of an effective learning environment. In *Proceedings of EdMedia 2016: World Conference on Educational Media and Technology* (pp. 1348–1353). Association for the Advancement of Computing in Education.

Bingham, A. J. (2023). From data management to actionable findings: A five-phase process of qualitative data analysis. *International Journal of Qualitative Methods, 22*, 1–12. https://doi.org/10.1177/16094069231183620

Bowman, R. F. (2018). Teaching and learning in a storytelling culture, the clearing house. *A Journal of Educational Strategies, Issues and Ideas*, *91*(3), 97–102. https://doi.org/10.1080/00098655.2017.1373547

Breitfeld, E., Potter, C. E., & Lew-Williams, C. (2021). Children simultaneously learn multiple dimensions of information during shared book reading. *Journal of Cognition and Development: Official Journal of the Cognitive Development Society*, *22*(5), 744–766. https://doi.org/10.1080/15248372.2021.1939353

Bruner, J. (1996). *The culture of education*. Harvard University Press. https://doi.org/10.2307/j.ctv136c601

Budzyna, D., & Buckley, D. (2023). *The whole child: Development in the early years.* ROTEL Project. https://rotel.pressbooks.pub/whole-child/

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Cantor, P., Osher, D., Berg, J., Steyer, I., & Rose, T. (2019). Malleability, plasticity, and individuality: How children learn, and develop in context. *Applied Developmental Science, 23*(4), 307–337. https://doi.org/10.1080/10888691.2017.1398649

Center on the Developing Child. (n.d.). *Brain architecture*. Harvard University. https://developingchild.harvard.edu/key-concept/brain-architecture/#:~:text=Learn%20how%20early%20experiences%20shape,more%20complex%20circuits%20and%20skills

Chaparro-Moreno, L. J., Lin, T. J., Justice, L. M., Mills, A. K., & Uanhoro, J. O. (2023). The influence of context on the abstraction level of children's conversations in the preschool classroom. *Early Education and Development*, *34*(3), 705–724. https://doi.org/10.1080/10409289.2022.2067429

Chowdhury, T. B. M, Holbrook, J., & Rannikmäe, M. (2020). Socioscientific issues within science education and their role in promoting the desire citizenry. *Science Education International, 31*(2), 203–208. https://doi.org/10.33828/sei.v31.i2.10

Ciecierski, L., Nageldinger, J., Bintz, W. P., & Moore, S. D. (2017). New perspectives on picture books. *Athens Journal of Education, 4(*2), 123–136. https://doi.org/10.30958/aje.4-2-2

Cohen, D. (2017). *How the child's mind develops*. Routledge. https://doi.org/10.4324/9781315201375

Copeland, D. E., Larson, K. G., & Palena, M. T. (2015). Remembering stories: Constructing elaborate situation models in memory. In K. Brakke & J. A. Houska (Eds.), *Telling stories: The art and science of storytelling as an instructional strategy* (pp. 40–48). American Psychological Association.

Crawford, P., Roberts, S., & Lacina, J. (2024). Picturebooks and young children: Potential, power, and practices. *Early Childhood Education Journal*, *52*, 1273–1279. https://doi.org/10.1007/s10643-024-01701-0

Dehaene, S. (2020). *How we learn: Why brains learn better than any machine-for now*. Penguin Random House LLC.

Demetriou, A. (2020). Abstracting abstraction in development and cognitive ability. *Behavioral and Brain Sciences*, *43,* Article e127. https://doi.org/10.1017/S0140525X19002930

Di Giuseppe, M., Fazio, X., Bowers, R., & Mok, W. Y. (2007). S*cience education: A summary of research, theories, and practice–A Canadian perspective*. Thomas Nelson.

Dumontheil, I. (2014). Development of abstract thinking during childhood and adolescence: The role of rostrolateral prefrontal cortex. *Developmental Cognitive Neuroscience*, *10*, 57–76. https://doi.org/10.1016/j.dcn.2014.07.009

Egan, K. (1986). *Teaching as storytelling: An alternative approach to teaching and curriculum in the elementary school*. Althouse Press.

Egan, K. (2005). *An imaginative approach to teaching*. Joey-Bass.

Egan, K., Bullock, S., & Chodakowski, A. (2016). Learning to teach, imaginatively: Supporting the development of new teachers through cognitive tools. *McGill Journal of Education*, *51*(3), 999–1012. https://doi.org/10.7202/1039625ar

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Ellis, J., Geiges, A., Gonzales-Zuñiga, S., Hare, B., Heck, S., Helfmann, L., Höhne, N., Missirliu, A., Han, F., & Pelekh, N. (2024). *Climate action tracker: 2024 warming projections global update*. Climate Analytics. https://ca1-clm.edcdn.com/CAT_2024-11-14_GlobalUpdate_COP29_2024-11-14-062702_mbaz.pdf

Fazio, X. (2023). Introduction. In X. Fazio (Ed.), *Science curriculum for the Anthropocene* (Vol. 2, pp.1–12). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-37391-6

Fazio, X., & Gallagher, T. (2019). Science and learning integration in elementary classrooms: Instructional enactments and student learning outcomes. *Research in Science Education, 49*(4), 959–976. https://doi.org/10.1007/s11165-019-9850-z

French, L. A., & Woodring, S. D. (2012). Science education in the early years. In O. N. Saracho & B. Spodek (Eds.)*, Handbook of research on the education of young children* (pp. 179–196). Routledge. https://doi.org/10.4324/9780203841198

Gleason, T., & White, R. (2023). Pretend play as abstraction: Implications for early development and beyond. *Neuroscience & Biobehavioural Reviews, 147,* Article 105090. https://doi.org/10.1016/j.neubiorev.2023.105090

Green, M. C. (2004, April 1). *Storytelling in teaching*. Association for Psychological Science. https://www.psychologicalscience.org/observer/storytelling-in-teaching

Gormley, K., Birdsall, S., & France, B. (2019). Socio-scientific issues in primary schools. *Set: Research Information for Teachers*, *2*, 11–19. https://doi.org/10.18296/set.0139

Hadzigeorgiou, Y. (2016). Narrative thinking and storytelling in science education. In Y. Hadzigeorgiou (Ed.), *Imaginative science education: The central role of imagination in science education* (pp. 83–119). Springer. https://doi.org/10.1007/978-3-319-29526-8_4

Harmon-Jones, E., & Mills, J. (2019). An introduction to cognitive dissonance theory and an overview of current perspectives on the theory. In E. Harmon-Jones (Ed.), *Cognitive dissonance: Reexamining a pivotal theory in psychology* (2nd ed., pp. 3–24). American Psychological Association. https://doi.org/10.1037/0000135-001

Hartwig, E. K. (2021). Puppet play therapy. In *Play therapy with children: Modalities for change* (pp. 107–124). American Psychological Association. https://doi.org/10.1037/0000217-008

Hensley, L. (2019, August 20). *Children who watch 'Sesame Street' may perform better at school, study finds*. Global News. https://globalnews.ca/news/5787769/watching-sesame-street-child-development-study/

Judson, G., Powell, R., & Robinson, K. (2021). Educating "perfinkers": How cognitive tools support affective engagement in teacher education. *Canadian Journal for the Scholarship of Teaching and Learning*, *12*(1), 1–15. https://doi.org/10.5206/cjsotlrcacea.2021.1.10793

Kahn, S. (2021). No child too young: A teacher research study of socioscientific issues implementation at the elementary level. In W. A. Powell (Ed.), *Socioscientific issues-based instruction for scientific literacy development* (pp. 1–30). IGI Global. https://doi.org/10.4018/978-1-7998-4558-4

Keenan, T., Evans, S., & Crowley, K. (2016). *An introduction to child development*. Sage. https://doi.org/10.4135/9781036235048

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Keough, K. L. (2024). *How pretend play helps children build skills*. Child Mind Institute. https://childmind.org/blog/how-pretend-play-helps-children-build-skills/

Killen, M., & Dahl, A. (2021). Moral reasoning enables developmental and societal change. *Perspectives on Psychological Science, 16*(6), 1209–1225. https://doi.org/10.1177/1745691620964076

Kinskey, M., & Zeidler, D. (2020). Elementary preservice teachers' challenges in designing and implementing socioscientific issues-based lessons. *Journal of Science Teacher Education*, *32*(3), 350–372. https://doi.org/10.1080/1046560X.2020.1826079

Kohlberg, L. (1981). *The philosophy of moral development: Moral stages and the idea of justice*. Harper & Row.

Koops, W. (2023). Developmental Psychology in cultural historical context–overview and further reflections. *Current Issues in Personality Psychology*, *11*(2), 130–136. https://doi.org/10.5114/cipp/159600

Korteling, J. E., & Toet, A. (2020). Cognitive biases. In S. Della Sala (Ed.), *Reference module in neuroscience and behavioural psychology* (pp. 610–619). Elsevier. https://doi.org/10.1016/B978-0-12-809324-5.24105-9

Kröger, T. & Nupponen, A. (2019). Puppet as a pedagogical tool: A literature review. *International Electronic Journal of Elementary Education, 11*(4), 393–401. https://doi.org/10.26822/iejee.2019450797

Krushelnycky, E. (2025). *The 'sanitization' of science education: Connecting theory and practice of socioscientific issues in elementary science classrooms* [Master's thesis, Brock University]. Scholaris. https://brocku.scholaris.ca/items/443ea725-423e-4490-86bf-bc23ddfa4d83

Krushelnycky, E., & Karrow, D. D. (2024). Science, technology, engineering, & mathematics, curricular integration, and the story form. *Future in Educational Research*, 3(1), 67–91. https://doi.org/10.1002/fer3.48

Kumar, P., & Kumar, P. (2024). Beyond entertainment: Examining the role of animation in fostering emotional intelligence. *Proceedings of Emerging Trends in Design & Arts (ICETDA, 2024)* (Vol. 2, pp. 73-79), *Poornima University, Jaipur*. https://icetda.poornima.edu.in/Proceeding%20ICETDA%202024.pdf

Landrum, R. E., Brakke, K. & M. A. McCarthy. (2019). The pedagogical power of storytelling. *Scholarship of Teaching and Learning in Psychology, 5*(3), 247–253. https://doi.org/10.1037/stl0000152

Larivière-Bastien, D., Aubuchon, O., Blondin, A., Dupont, D., Libenstein, J., Séguin, F., Tremblay, A., Zarglayoun, W., Herba, C. M., & Beauchamp, M. H. (2022). Children's perspectives on friendships and socialization during the COVID-19 pandemic: A qualitative approach. *Child: Care, Health and Development, 48*(6), 1017–1030. https://doi.org/10.1111/cch.12998

Larragueta, M., & Ceballos-Viro, I. (2018). What kind of book? Selecting picture books for vocabulary acquisition. *The Reading Teacher, 72*(1), 81–87. https://doi.org/10.1002/trtr.1681

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267–1287. https://doi.org/10.1080/09500690500439348

Lillard, A. S. (2022). Pretending at hand: How children perceive and process puppets. *Cognitive Development*, *63*. https://doi.org/10.1016/j.cogdev.2022.101202

Lindsey, R., & Dahlman, L. (2025, May 29). *Climate change: Global temperature*. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

LoBue, V., Nishida, T., Chiong, C., DeLoache, J. S., & Haidt, J. (2011). When getting something good is bad: Even three-year-olds react to inequality. *Social Development (Oxford, England)*, *20*(1), 154–170. https://doi.org/10.1111/j.1467-9507.2009.00560.x

Ma, H. K. (2013). The moral development of the child: An integrated model. *Frontiers in Public Health*, *1*. Article 57. https://doi.org/10.3389/fpubh.2013.00057

Martinovic, D., & Milner-Bolotin, M. (2022). Problematizing STEM: What it is, what it is not, and why it matters. In C. Michelsen, A. Beckmann, V. Freiman, U. Thomas Jankvist, & A. Savard (Eds.), *Mathematics and its connections to the arts and sciences (MACAS) 15 years of interdisciplinary mathematics education* (pp. 135–162). Springer Nature. https://link.springer.com/chapter/10.1007/978-3-031-10518-0_8

Masamba, H. (2024). Cultural influences on parenting styles and child development. *International Journal of Humanity and Social Sciences*, *2*(3), 15–27. https://doi.org/10.47941/ijhss.1783

McArthur, B., Tough, S., & Madigan, S. (2022). Screen time and developmental and behavioral outcomes for preschool children. *Pediatric Research, 91*, 1616–1621. https://doi.org/10.1038/s41390-021-01572-w

McCrory, A. (2014). *Investigating the moral and scientific thinking of 7-8 year olds when taught socio-scientific issues related to energy and genetics* [Unpublished doctoral dissertation, University of London Institute of Education]. UCL Discovery. https://discovery.ucl.ac.uk/id/eprint/10034050

McCrory, A., & Reiss, M. J. (2023). *The place of ethics in science education*. Bloomsbury Publishing.

McKnight, D. M. (2010), Overcoming "ecophobia": Fostering environmental empathy through narrative in children's science literature. *Frontiers in Ecology and the Environment, 8*, 10–15. https://doi.org/10.1890/100041

McLuhan, M. (1964). *Understanding media: The extensions of man*. McGraw-Hill.

Metz, K. E. (1997). On the complex relation between cognitive development research and children's science curricula. *Review of Educational Research, 67*(1), 151–163. https://doi.org/10.2307/1170622

Miller, P. H. (2022). Developmental theories: Past, present, and future. *Developmental Review*, *66*, 1–13. https://doi.org/10.1016/j.dr.2022.101049

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Montag, J., Jones, M. N., & Smith, L. B. (2015). The words children hear: Picture books and the statistics for language learning. *Psychological Science, 26*(9), 1489–1496. https://doi.org/10.1177/0956797615594361

Muppalla, S. K., Vuppalapati, S., Reddy Pulliahgaru, A., & Sreenivasulu, H. (2023). Effects of excessive screen time on child development: An updated review and strategies for management. *Cureus, 15*(6). Article e40608. https://doi.org/10.7759/cureus.40608

National Association for the Education of Young Children (NAEYC). (n.d.). *DAP: Defining developmentally appropriate practice*. https://www.naeyc.org/resources/position-statements/dap/definition

Niland, A. (2023). Picture books, imagination and play: Pathways to positive reading identities for young children. *Education Sciences*, *13*(5), Article 511. https://doi.org/10.3390/educsci13050511

Ozdemir, E. (2022). Animated concept cartoons as a starter for cognitive conflict in online science learning: A case of circular motion. *Journal of Science Learning, 5*(2), 242–249. https://doi.org/10.17509/jsl.v5i2.41191

Padamsi, Z. (2017). Why pursue STEM when we have STSE? A Canadian perspective. *Journal for Activist Science and Technology Education*, *8*(1), 18–20.

Parker, K. L. & Ackerman, B. E. (2007). Character education in literature-based instruction. *Faculty Publications and Presentations, 33*, 1–3. http://digitalcommons.liberty.edu/educ_fac_pubs/33

Pedretti, E. (2003). Teaching science, technology, society, and environment (STSE) education. In D. L. Zeidler (Ed), *The role of moral reasoning on socioscientific issues and discourse in science education* (Vol. 19, pp. 219–239). Springer Nature. https://doi.org/10.1007/1-4020-4996-X_12

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

Peleg, R., Østern, A.-L., Strømme, A., & Baram Tsabari, A. (2018). Drama as a learning medium in science education. In O. Tsivitandou, P. Gray, E. Rybska, L. Louca, & C. Constantinou (Eds.), *Professional development for inquiry-based science teaching and learning: Contributions to science education research* (Vol. 5, pp. 65–83). Springer. https://doi.org/10.1007/978-3-319-91406-0_4

Pihkala, P. (2024). Emotional and affective issues in environmental and sustainability education. In L. H. Meyer (Ed.), *Oxford bibliographies in education*. Oxford University Press. https://doi.org/10.1093/obo/9780199756810-0310

Ponti, M. (2023). Screen time and preschool children: Promoting health and development in a digital world. *Paediatric & Child Health, 28*(3). 184–192. https://doi.org/10.1093/pch/pxac125

Presley M. L., Sickel, A. J. Muslu, N. Merle-Johnson, D., Witzig, S. B., & Sadler, T. D. (2013). A framework for socio-scientific issues-based education. *Science Educator, 22*(1), 26–32. https://eric.ed.gov/?id=EJ1062183

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Prince, S. A., Melvin, A., & Thompson, W. (2020). Sedentary behaviour surveillance in Canada: Trends, challenges and lessons learned. *International Journal of Behavioral Nutrition and Physical Activity, 17,* Article 34. https://doi.org/10.1186/s12966-020-00925-8

Råde, A. (2021). Theories supporting the use of puppets as a pedagogical tool with young children. *Universal Journal of Educational Research*, *9*(7), 1359–1368. https://doi.org/10.13189/ujer.2021.090702

Roberts, D., & Bybee, R. (2014). Scientific literacy, science literacy and science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 545–558). Routledge. https://doi.org/10.4324/9780203097267

Rowcliffe, S. (2004). Storytelling in science. *School Science Review, 86*(314), 121–126. https://www.academia.edu/5051952/Storytelling_in_science

Ryan, S., & Grieshaber, S. (2004). It's more than child development: Critical theories, research, and teaching young children. *YC Young Children*, *59*(6), 44–52. https://www.jstor.org/stable/42729844

Saçkes, M., Trundle, K., & Flevares, L. (2009). Using children's literature to teach standard-based science concepts in early years. *Early Childhood Education Journal*, *36*, 415–422. https://doi.org/10.1007/s10643-009-0304-5

Sadler, T. D., Dawson, V. (2012). Socio-scientific issues in science education: Contexts for the promotion of key learning outcomes. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education* (Vol. 24, pp. 709–899). Springer. https://doi.org/10.1007/978-1-4020-9041-7_53

Sanvictores, T., & Mendez, M. D. (2022). *Types of parenting styles and effects on children*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK568743/

Schon, D. (2022, October 24). *What is developmentally appropriate in early childhood?* School Administrators of Iowa. https://www.sai-iowa.org/news/what-is-developmentally-appropriate-in-early-childhood

Science Council of Canada. (1984). *Science for every student: Educating Canadians for tomorrow's world* (Report No. 36). https://www.uottawa.ca/research-innovation/sites/g/files/bhrskd326/files/2022-08/report-no.-36-science-for-every-student-educating-canadians-for-tomorrows-world.pdf

Scott, H. K., & Cogburn, M. (2023). Piaget. In *StatPearls*. StatPearls Publishing. https://pubmed.ncbi.nlm.nih.gov/28846231/

Seifert, K. L. (2012). Cognitive development and the education of young children. In O. N. Saracho & B. Spodek (Eds.), *Handbook of research on the education of young children* (pp. 19–32). Routledge. https://doi-org./10.4324/9780203841198

Sheposh, R. (2022). *Abstraction*. EBSCO. https://www.ebsco.com/research-starters/religion-and-philosophy/abstraction

Shivhare, R., & Kumar, C. A. (2016). On the cognitive process of abstraction. *Procedia Computer Science*, *89*, 243–252. https://doi.org/10.1016/j.procs.2016.06.051

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Simmons, N. (2017). Axial coding. In M. Allens (Ed.) *The sage encyclopedia of communication research methods* (Vol. 4, pp. 80–82). SAGE Publications Inc. https://doi.org/10.4135/9781483381411.n33

Sjöström, J. (2024). Vision III of scientific literacy and science education: an alternative vision for science education emphasising the ethico-socio-political and relational-existential. *Studies in Science Education*, *61*(2), 239–274. https://doi-org./10.1080/03057267.2024.2405229

Sobel, D. (2008). *Childhood and nature: Design principles for educators*. Stenhouse Publishers.

Sohn, L. N., Rodriquez, R. C., & Juarez, L. M. (2018). Connecting children's literature and science education through writing. *Texas Association for Literacy Education Yearbook, 5*, 110–121. https://eric.ed.gov/?id=EJ1290998

Speaight, G. (2023). *Puppetry*. Britannica. https://www.britannica.com/art/puppetry

Spielger, J. (2020). *Picture books can open doors to tough topics*. Urban Libraries Council. https://www.urbanlibraries.org/blog/picture-books-can-open-doors-to-tough-topics

Spiteri, J. (2021). Can you hear me? Young children's understanding of environmental issues. *International Studies in Sociology of Education, 30*(1-2), 191–213. https://doi.org/10.1080/09620214.2020.1859401

Stanborough, R. (2026). *Abstract thinking: What it is, why we need it, and when to rein it in*. Healthline. https://www.healthline.com/health/abstract-thinking

Stewart, C., & Koopmans, H. (2025). Critical picture book literacy. *Journal of Visual Literacy*, *44*(1), 71–93. https://doi.org/10.1080/1051144X.2025.2458444

Strife, S. (2012). Children's environmental concerns: Expressing ecophobia. *The Journal of Environmental Education*, *43*, 37–54. https://doi.org/10.1080/00958964.2011.602131

Strouse, G. A., Nyhout, A., & Ganea, P. A. (2018). The role of book features in young children's transfer of information from picture books to real-world contexts. *Frontiers in Psychology*, *9,* Article 50. https://doi.org/10.3389/fpsyg.2018.00050

Suh, R. (2019). *Abstract thinking skills*. EBSCO. https://www.ebsco.com/research-starters/religion-and-philosophy/abstract-thinking-skills

Thompson, A. (2022, February 1). *How climate change will hit younger generations*. Scientific American. https://www.scientificamerican.com/article/how-climate-change-will-hit-younger-generations/

Tippett, C. D., Milford, T. M., & Yore, L. D. (2019). Epilogue: The current context of Canadian science education and issues for further consideration. In C. D. Tippett & T. M. Milford (Eds.), *Science education in Canada: Consistencies, commonalities, and distinctions* (pp. 311–337). Springer International Publishing. https://doi.org/10.1007/978-3-030-06191-3_15

Turan, F., & Ulutas, I. (2016). Using storybooks as a character education tools. *Journal of Education and Practice, 7*(15), 169–176. https://files.eric.ed.gov/fulltext/EJ1103139.pdf

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Ungvarsky, J. (2025). *Sociodramatic play*. EBSCO. https://www.ebsco.com/research-starters/social-sciences-and-humanities/sociodramatic-play

UNICEF. (n.d.). The formative years: UNICEF's work on measuring early childhood development. https://data.unicef.org/wp-content/uploads/2019/09/Formative-Years-ECD-Brochure-EN.pdf

United Nations. (n.d.). *Causes and effects of climate change*. Retrieved November 24, 2025, from https://www.un.org/en/climatechange/science/causes-effects-climate-change

Vadeboncoeur, J. (1997). Child development and the purpose of education: A historical context for constructivism in teacher education. In V. Richardson (Ed.), *Constructivist teacher education: Building a world of new understandings* (pp. 15–38). Taylor & Francis. https://doi.org/10.4324/9780203973684-9

Verriour, P. (1990). Storying and storytelling in drama. *Language Arts, 67*(2), 144–150. https://www.jstor.org/stable/41961715

Walan, S., & Enochsson, A. B. (2019). The potential of using a combination of storytelling and drama, when teaching young children science. *European Early Childhood Education Research Journal*, *27*(6), 821–836. https://doi.org/10.1080/1350293X.2019.1678923

Yilmaz, O., Bahçekapili, H. G., & Sevi, B. (2019). Theory of moral development. In T. Shackelford & V. Weekes-Shackelford (Eds.), *Encyclopedia of evolutionary psychological science* (pp. 1–5). Springer. https://doi.org/10.1007/978-3-319-16999-6_171-1

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 1, pp. 697–721). Routledge.

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. (2023). Exploring and expanding the frontiers of socioscientific issues. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman. *Handbook of research on science education* (Vol. 3, pp. 899–930). Routledge.

Zhang, J. (2022). The influence of Piaget in the field of learning science. *Higher Education Studies, 12*(3), 162–168. https://doi.org/10.5539/hes.v12n3p162

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Inviting Controversy into Canadian Classrooms: Socioscientific Issues and Navigating Misinformation

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Abstract

In an era of widespread misinformation and divisive public discourse, navigating socioscientific issues (SSI) such as climate change and vaccinations has become increasingly complex. This paper explores the crucial role that science education plays in preparing individuals to engage with SSI. It addresses two questions: How might teachers prepare students to analyze SSI and become effective information consumers and decision-makers, and how might teachers be prepared to meet the challenges of implementing controversial SSI? Drawing on the author's experiences teaching and offering professional development to teachers, as well as what was learned from conducting a scoping review on misinformation (Brown, 2026), this reflective commentary argues that science education must expand efforts to invite nuanced and controversial SSI into classrooms to better prepare Canadians to engage with one another and with these key issues. Student preparation could include increased emphasis on SSI, a focus on developing information/digital/media literacy, fostering intellectual virtues, and connecting SSI with the Nature of Science (NoS). Teachers' efforts to integrate SSI could be bolstered through curriculum and assessment modifications, professional development, resource creation and sharing, and enhanced support from administrators. This paper calls on teachers, teacher educators, school administrators, and science education researchers to advance this critical work.

Keywords: socioscientific issues, science education, misinformation, scientific literacy, nature of science

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Inviting Controversy into Canadian Classrooms: Socioscientific Issues and Navigating Misinformation

Canadians can access large volumes of information online and through social media, yet they face a deluge of science and health misinformation (Bilodeau & Khalid, 2024; Statistics Canada, 2023). Socioscientific issues (SSI) such as climate change and vaccinations are increasingly divisive (Azevedo & Jost, 2021; Boulianne & Belland, 2022), and the situation is worsened by political leaders and governments that actively spread false information (disinformation)[1] related to these topics (Hornsey et al., 2020; Strudwicke & Grant, 2020). Misinformation has serious consequences for Canadians' health, well-being, and the environment. For example, misinformation around climate change may lead to public doubt or confusion and impact support for policy or climate action (Cook et al., 2018; Oreskes & Conway, 2010). Similarly, misleading health claims can delay or prevent individuals from seeking medical treatment or preventative care (Canadian Medical Association [CMA] & Abacus Data, 2025; Kemei et al., 2023). Unfortunately, the issue seems to be getting worse. CMA and Abacus Data (2025) warn that many Canadians are susceptible to health misinformation, and that "over the past year, Canadians' encounters with health misinformation has [*sic*] increased significantly" (p. 3).

Science education plays a crucial role in addressing misinformation and in preparing future citizens to navigate complex SSI (Allchin, 2023b; Osborne & Pimentel, 2022). However, in this chaotic and evolving information environment, how might teachers prepare students to analyze SSI and become effective information consumers and decision-makers? Further, how might teachers be prepared to meet the challenges of implementing controversial SSI? This paper offers a reflective commentary on these issues, weaving together what I learned from my experiences teaching high school science, offering professional development (PD) to teachers on a controversial socioscientific issue (i.e., vaccinations during COVID-19), and conducting a scoping review on science education's responses to misinformation (Brown, 2026). I argue that efforts to bring nuanced and controversial SSI into classrooms must be expanded if teachers are to prepare future Canadians to critically engage with the science, health, and environmental issues that impact us all.

Background: Weaving Together Science Literacy, SSI and Responding to Misinformation

Misinformation is a complex problem that requires a multidisciplinary response. Science education is well situated to respond to misinformation by supporting citizens' capacity to evaluate information and make decisions (Allchin, 2023b; Feinstein & Waddington, 2020; Lazer et al., 2018). One lens through which this work is taken up is scientific literacy (Höttecke & Allchin, 2020; Sharon & Baram-Tsabari, 2020). There is no unified definition of scientific literacy, though Feinstein (2011) conceptualizes scientifically literate individuals as *competent outsiders* with respect to science. Competent outsiders recognize the limits of their knowledge and expertise, understand how science relates to their lives, and can engage with scientific information in ways that help them participate in decision-making around SSI (Feinstein, 2011; Feinstein et al., 2013). Thus, this view of scientific literacy acknowledges that individuals are socially and culturally situated, and that decision-making around SSI involves evaluating claims and sources of

[1] While distinctions between *disinformation*, which is spread with intent to deceive, and *misinformation*, which is spread unintentionally, are well documented (Barzilai & Chinn, 2020; Wardle & Derakhshan, 2017), this commentary uses misinformation as an umbrella term unless intent is known. From the perspective of the information consumer, it is not always known whether there was intent to deceive.

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information as well as considering other factors (personal, social, economic, ethical) (Osborne & Pimentel, 2022; Sharon & Baram-Tsabari, 2020).

Claim evaluation and decision-making around SSI have become increasingly complex, given the realities of modern information communication, including biased news media, spin, and reliance on online sources such as social media, which bypass the fact-checking functions of traditional news media (Höttecke & Allchin, 2020; Oreskes & Conway, 2010). In response, educators have incorporated information literacy (Gu & Feng, 2022; Julien & Barker, 2009; Klucevsek, 2017) and digital/media literacy skills (Hodson, 2011; Jarman & McClune, 2007; Reid & Norris, 2016) into science literacy frameworks. Authors (e.g., Höttecke & Allchin, 2020; Klucevsek, 2017) argue that science education must emphasize critical information/digital/media skills for navigating the current information environment, such as source evaluation, understanding the internet and social media, and identifying tactics[2] used to spread disinformation. Thus, how scientific literacy is characterized has evolved: not only do individuals need to understand how science works (the nature of science [NoS]), including how science is communicated and miscommunicated, but they must also be able to identify science-related misinformation, analyze information from multiple (conflicting) sources, and engage in discourse and everyday decision-making around SSI in increasingly polarized environments (Allchin, 2023b; Höttecke & Allchin, 2020; Osborne & Allchin, 2025; Sharon & Baram-Tsabari, 2020).

Questions and Context: Framing This Reflective Commentary

If our aim as science educators and teacher educators is to support the development of scientifically literate citizens who can engage meaningfully in decision-making around complex SSI, then how might we take up this work? Specifically, this paper explores two questions:

1. How might teachers prepare students to analyze SSI and become effective information consumers and decision-makers?
2. What challenges are inherent in the implementation and enactment of SSI in teaching practice, and how might teachers be prepared for these challenges?

In response to these questions, this paper offers a reflective commentary drawn from three key sites of reflection. The first was my experience teaching high-school science in Alberta, and in particular, teaching Science 24 Unit C (Disease Defense & Human Health), which includes discussion around social and economic impacts of pandemic diseases, exploration of immunity, vaccinations, and analysis of the impact of public health initiatives (Alberta Education, 2014). I recalled and journalled my experiences related to teaching this content and engaging students in discussions around SSI. The next site of reflection was my experience creating and facilitating PD sessions with pre-service and in-service teachers within Canada (12 sessions between November 2021 and February 2024).[3] Sessions focused on sharing resources[4] and teaching strategies to help address science and health misinformation and supporting teachers to prepare students to engage

[2] Some examples of such tactics include casting doubt on the scientific consensus, fear mongering, and cherry-picking data (e.g., see Cook et al., 2017; Lewandowsky & van der Linden, 2021; Oreskes & Conway, 2010). These deliberate efforts of deception by politicians, companies, and special-interest groups for economic and/or political gain muddy the waters around SSI, making it more difficult for citizens to locate evidence-based information and engage in decision-making (Gotlib & Groenhout, 2022; Hansson, 2017; Oreskes & Conway, 2010; Scheufele & Krause, 2019).
[3] Data on the number of participants who attended the sessions is not available, nor is the proportion of attendees who were pre-service versus in-service teachers.
[4] These include videos, lesson ideas, and activities developed in partnership with CMASTE and Glyconet. For access to resources, go to: https://sites.google.com/ualberta.ca/cmaste/teacher-resources?authuser=0.

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critically with SSI, with a focus on COVID-19 and vaccines. Sessions were adapted to different delivery formats (online or in-person/hybrid) and varied in length from 75 minutes to three hours. Session titles included: *Vaccines & Hesitancy: Teaching for Critical Thinking* and *Critical Thinking Using Socioscientific Issues (Including COVID).* My reflection on these sessions included reviewing the content, the written notes I kept during development and delivery, the changes made over time, and their implications in relation to the guiding questions of this paper.

Finally, the third site of reflection was my experience conducting a scoping review on science education's responses to misinformation (Brown, 2026). This paper does not present details on the methodology and findings of the scoping review; instead, it draws on my notes and reflections on what I learned while undertaking the review and how it might inform how I approach preparing students or teachers to engage with SSI. Further, in preparing this manuscript, I recognized that literature for the scoping review was limited in several ways: it needed to be updated with more recent literature (as the review included literature up to December 2024), it focused more broadly on science education efforts (though discussion around/exploration of SSI was identified as a promising approach to build resilience to misinformation, see Brown, 2026), and it was not specifically focused on the Canadian context. Consequently, I conducted an additional literature search via Google Scholar, using the terms socio-scientific OR SSI OR socioscientific AND Canada.[5] Thus, this paper draws on science education literature but does not have the methodological rigour of a scoping review. I acknowledge that relevant literature is missing, particularly literature for notable American scholars who focus on SSI, because my focus is on the Canadian context.

This paper offers my perspectives on the questions posed, based on my reflections on a broad but not exhaustive sampling of literature, my experiences as a former high-school science educator, a current pre-service and in-service teacher educator, and an early-career researcher with a deep interest in combating science and health misinformation. It represents my current thinking on this issue and is an attempt to bring together these three areas of my professional learning and growth to generate potential paths forward and points for discussion. It is also an invitation for pre-service and in-service teachers, teacher educators, school administrators, and science education researchers to continue conversations about how we can support students and teachers in engaging with and navigating complex, and often controversial SSI.

Question 1: How Might We Prepare Students to Critically Analyze SSI?

Based on my reflections, four key themes emerged related to preparing students to critically analyze SSI. These were increasing curricular emphasis on SSI, integrating information/digital/media literacy into science education contexts, fostering intellectual virtues such as open-mindedness and skepticism, and explicitly connecting SSI and NoS instruction. Insights from my experiences teaching and offering PD sessions are woven throughout the discussion to provide context and describe how this work might be taken up in classrooms.

Increased Emphasis on SSI

Current science curricula are criticized for underemphasizing SSI (Höttecke & Allchin, 2020; Kienhues et al., 2020). In response, authors (e.g., Duschl, 2020; Hodson, 2020; Lima & Nascimento, 2022; Viehmann et al., 2024) call for greater integration of SSI and the social context of science knowledge development. Viehmann et al. (2024) argue that, even when SSI is part of

[5] Last search using these terms: May 19, 2026.

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the curriculum, it may neglect future scenarios, risk evaluation, and translating knowledge into action, leaving students unprepared to navigate future ethical, social, or environmental challenges. This may apply to the Canadian education context, where a scoping review highlighted that climate change coverage is inconsistent across curricula (Field et al., 2023). This suggests that expansion of SSI in Canadian curriculum documents may be warranted, though additional research is needed to explore the coverage of specific SSI (including controversial SSI such as vaccines) in Canadian curricula.

From my perspective as a former high-school science teacher and current teacher educator/PD facilitator, students need opportunities to discuss and explore increasingly complex SSI as they move through the education system because they are curious about—and impacted by—these topics, even if curriculum documents do not address them. If students are left to navigate complex SSI on their own, they dive into *epistemically unfriendly environments* (i.e., spaces where misinformation is rampant, such as social media) with limited preparation (Chinn et al., 2021; Kalu-Mamji et al., 2024). Instead, teachers can introduce students to controversial SSI in epistemically friendly environments where students feel safe asking questions, changing their minds, and learning to evaluate claims. Science teachers are well situated to help students explore scientific concepts related to SSI, facilitate discussions, scaffold critical thinking, and support the development of skills needed to engage with more controversial topics and move into deeper waters (i.e., epistemically unfriendly environments) over time (Chinn et al., 2021). In my conversations with teachers, I have seen that many already do this work by bringing in current events and topics of interest to students; however, the extent of SSI coverage across classrooms varies. Thus, expanding curricular guidelines around SSI coverage in Canada could support consistent opportunities for students to practice navigating complex issues before they graduate. Teacher education may also support increased inclusion of SSI in classrooms, as discussed in a subsequent section.

Developing Information/Digital/Media Literacy

Another crucial aspect of preparing students to engage with nuanced SSI is cultivating information/digital/media literacy skills. Information literacy refers to the cognitive skills required to find, retrieve, analyze and use information (American Library Association [ALA], 2006; Association of College and Research Libraries [ACRL], 2016). Digital/media literacy refers to an individual's ability to access, critically evaluate, use, and create digital media/content (Allchin, 2023b; Höttecke & Allchin, 2020; Phippen et al., 2021; Wuyckens et al., 2022). Some students and teachers may lack information or digital literacy skills (Belova et al., 2022; Breakstone et al., 2018; Burron & Pegg, 2021). However, evidence shows that educational interventions can support skill development (Scheibenzuber et al., 2021; Tseng et al., 2021). Specific areas of information/digital/media literacy instruction that may support individuals to navigate conflicting science and health information include: knowledge of disinformation tactics (e.g., use of fake experts, manufacturing uncertainty; see Table 1) and features of the internet/social media (e.g., algorithms pushing content) (Allchin, 2023b; Lewandowsky et al., 2017; Estigarribia et al., 2022); evaluating source credibility (Brante & Strømsø, 2018; Estigarribia et al., 2022; Osborne & Pimentel, 2023); and employing strategies of expert fact checkers (Breakstone et al., 2018; Scheibenzuber et al., 2021).

From a practitioner standpoint, if citizens require information/digital/media literacy skills to effectively navigate SSI in their everyday lives (Allchin, 2023b; Osborne & Pimentel, 2023), then SSI are the logical context for developing these skills. Specifically, in the PD sessions I have

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offered to teachers, I have argued that social media and online sources of information should be leveraged, wherever possible, to bring emerging SSI into science classrooms. Young people already use online sources to acquire science and health information (Belova et al., 2022; Morote & Hernández, 2022), and these sources provide more authentic environments to engage with SSI than textbooks (Belova et al., 2022). For example, educators can utilize web searches, social media platforms, YouTube, and podcasts to introduce different arguments and perspectives on SSI while scaffolding students to develop their information/digital/media literacy skills. This could include evaluating sources of information by considering credentials, education, experience, track-record/reputation among peers, and conflicts of interest (Allchin, 2023a; Brante & Strømsø, 2018; Herrick et al., 2023; Osborne & Pimentel, 2023). Teachers could also model skills like *click-restraint* (skimming search results and evaluating different sources before clicking on one) and *lateral reading* (consulting other sources/websites/books for information about an author's credibility or about a particular claim) (Barzilai et al., 2023; Breakstone et al., 2018; Scheibenzuber et al., 2021). Anecdotally, teachers I have worked with were encouraged by how easily they could integrate and model these skills as a part of activities they were already doing in their classrooms. However, time constraints may limit teachers' ability to give students opportunities to practice and refine these skills (see Question 2).

Fostering Intellectual Virtues

Based primarily on my reflections on conducting the scoping review (see Brown, 2026), intellectual virtues such as open-mindedness, skepticism, and intellectual humility play an important role in effectively navigating contentious, politically charged SSI (Lapsley & Chaloner, 2020; Lombard et al., 2020; Sharon & Baram-Tsabari, 2020). Skepticism and open-mindedness involve suspending judgement until a claim can be investigated and being willing to follow the evidence and change one's perspective (if warranted) (Lapsley & Chaloner, 2020; Sharon & Baram-Tsabari, 2020). Intellectual humility can be described as a "willingness to own up to one's intellectual limitations, to embrace fallibility and be ready to yield convincing evidence or stronger argument" (Lapsley & Chaloner, 2020, p. 133). Authors (e.g., Lombard et al., 2020; Sharon & Baram-Tsabari, 2020) argue that science education should focus on scaffolding the development of these virtues as a response to misinformation. Some promising pedagogical approaches to support the development of these virtues include facilitating discussion around SSI, exploring alternative explanations, reflecting on bias, and perspective-taking (Lombard et al., 2020; Viehmann et al., 2024).

Related to the virtues of open-mindedness, skepticism, and intellectual humility, authors (e.g., Barzilai et al., 2023; Beauvais, 2022; Estigarribia et al., 2022; Herrick et al., 2023; Lombardi et al., 2016; Scheibenzuber et al., 2021; Tabak, 2020; Tseng, 2018) also described the importance of teaching students about their thinking. There is evidence that helping students to reflect on and slow down their thinking (e.g., through prompts or targeted questions) can support them to more effectively evaluate conflicting information and engage in decision making around SSI (e.g. Barzilai & Chinn, 2020; Chinn et al., 2020; Estigarribia et al., 2022; Flener-Lovitt, 2014; Lapsley & Chaloner, 2020; Lombardi et al., 2016; Sinatra & Lombardi, 2020; Tseng, 2018). Further, supporting students to reflect on and recognize the limits of their own knowledge and when to defer to experts (i.e., practice intellectual humility/epistemic dependence) may also help them navigate complex SSI (Allchin, 2023b; Barzilai & Chinn, 2020; Bromme & Goldman, 2014; Chinn et al., 2021; Höttecke & Allchin, 2020; Kienhues et al., 2020; Osborne & Pimentel, 2022).

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For educators, supporting the development of intellectual virtues in classroom contexts relates to how we cultivate the environment and the modelling we do for our students over the term. Teachers can encourage curiosity and ask questions in their classroom, provide space to respectfully discuss multiple perspectives, and provide examples (personal or historical) to demonstrate why it is a good thing (and, in fact, core to the practice of science) to change your mind on a science/health issue when new evidence emerges. Chinn et al. (2021) suggest: "as a start, teachers can bring in data that are messy and information that is questionable. Or teachers might hold explicit discussions about core intellectual virtues… that are relevant to their planned class activities" (p. 51). When thoughtfully planned, these virtues can be incorporated into activities, discussions, and assignments throughout the term, while meeting knowledge and skill outcomes in curricula.

Connecting SSI and the Nature of Science (NoS)

Another theme that emerged from my reflections, largely based on the literature I reviewed (see Brown, 2026), was the intertwining of SSI and NoS. SSI can be leveraged to develop NoS understanding (Maia et al., 2021) and, conversely, a nuanced NoS understanding may support citizens navigating complex SSI (Höttecke & Allchin, 2020). Further, NoS instruction may help to combat misinformation, as harbouring misconceptions about science is associated with denialist rhetoric and rejection of scientific expertise (Feinstein & Waddington, 2020; Kienhues et al., 2020). Discussion continues about what NoS instruction should entail (Allchin, 2011; Lederman & Lederman, 2014; Stroupe et al., 2024); however, some NoS ideas may help students navigate SSI and spot misinformation. These include:

- Scientific knowledge is tentative and evolving as new evidence emerges. Science cannot provide 100% certainty or absolute proof (Allchin, 2023b; Bellocchi et al., 2022; Benjamin & McLean, 2022; Duschl, 2020; Feinstein & Waddington, 2020; Lombard et al., 2020; Maia et al., 2021).
- Scientific knowledge is trustworthy because experts develop it through consensus-building. Consensus does not mean that all experts agree. Experts are people who have specialized knowledge gained through education (graduate degrees), training, and experience working and/or conducting research in the field (Allchin & Zemplén, 2020; Benjamin & McLean, 2022; Cook et al., 2017; Kienhues et al., 2020; Osborne & Pimentel, 2023; Valladares, 2022).
- Consensus in the scientific community differs from public consensus. Public debate/controversy about science or health topics does not necessarily reflect the perspectives of the scientific community (Höttecke & Allchin, 2020; Lewandowsky et al., 2017; Scheufele & Krause, 2019; Sharon & Baram-Tsabari, 2020).
- The nuance, context and complexity of scientific research/topics are often lost in translation to lay audiences. Scientists/researchers communicate and debate ideas through peer-reviewed literature and presentations at academic conferences (Allchin, 2023b; Benjamin & McLean, 2022; Höttecke & Allchin, 2020; Osborne & Pimentel, 2023).

SSI provide rich opportunities for teachers to address multiple NoS learning outcomes in curricula (in addition to knowledge and skill/attitude outcomes) and address potential misinformation students may encounter, as explored in Table 1. Ideas for classroom implementation are also described in Table 1.

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Table 1

Exploring Core NoS Ideas Through SSI as a Response to Some Common Mis/Disinformation Tactics

Mis/Disinformation Tactic	Related NoS Idea	Ideas for Classroom Implementation
Unrealistic expectations/ burden of proof. e.g., *"I won't get vaccinated unless there is a guarantee of no side effects."*	Scientific knowledge is tentative and evolving, but trustworthy. Science cannot provide 100% certainty or absolute proof.	Discuss how knowledge is developed in science (show the struggle, see Duschl, 2020). Explore the limits of science (science can provide pretty good knowledge, but not absolute proof). Use local/current SSI to practice weighing evidence *(e.g. should drinking water be fluoridated?).*
Use of fake experts or unqualified individuals weighing in on science and health topics. e.g., *Someone claiming to be a chiropractor on YouTube tells you that home-made sunscreen is safer than commercially available sunscreen.*	Scientific knowledge is trustworthy because it is developed through consensus building among experts. Experts have specialized knowledge gained through education, training, and experience working in the field.	Use historical examples that describe the gradual development of scientific knowledge. Teach students about what expertise means and how to evaluate expertise in science/health. Have students make evaluations of experts/non-experts on SSI/topics related to curricula. Use *lateral reading* to gather information on sources (Scheibenzuber et al., 2021).
Fear mongering/manufacturing uncertainty. e.g., *Cigarette companies continued to cast doubt on the scientific consensus that cigarettes were harmful to health (see Oreskes & Conway, 2010).*	There is a difference between consensus in the scientific community and consensus in the public. Public debate/controversy about science topics does not mean it is controversial in the scientific community.	Differentiate between scholarly and non-scholarly sources of information. Teach students about false-balance media coverage (Cook et al., 2017; Höttecke & Allchin 2020; Koehler, 2016). Use examples of SSI where the body of scientific evidence was/is not well reflected in public discourse: climate change, GMO's, cigarettes, sunscreen, raw milk.
Appealing to emotion, hyping and sensationalizing content to encourage clicks/likes/shares. e.g., *Synthetic chemical in consumer products linked to early death, study finds (LaMotte, 2021).*[6]	The nuance, context and complexity of scientific research is often lost in translation to lay audiences.[a]	Have students compare and discuss popular articles and the scientific (scholarly) articles they are based on (see Lombard et al., 2020). Prompt students to pause and consider the trustworthiness of information sources and the reason information is being shared (Herrick et al., 2023; Osborne & Pimentel, 2022; Vamanu & Zak, 2022).

Note. Mis/disinformation tactics identified in this table were derived from a variety of sources, including Cook et al. (2017), Lewandowsky and van der Linden (2021), and Oreskes and Conway

[6] For more information on why this headline is misleading, see American Chemistry Council (2021).

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(2010). Table 1 did not differentiate between misinformation and disinformation, as some tactics/ways of thinking (e.g., unrealistic expectations) could apply in both contexts.

[a] Journalists and others who translate scholarly research to lay audiences may unintentionally misrepresent science (misinformation). In contrast, others deliberately use tactics like appealing to emotion, hyping, or sensationalizing content to spread false information (disinformation).

Question 2: How Might Teachers Be Prepared for the Challenges Inherent in Implementing SSI?

Based on my reflections, challenges faced by teachers related to the implementation of SSI may include lack of confidence related to teaching controversial SSI, concern over caregiver/community backlash, gaps in knowledge related to SSI, inadequate resources for introducing emerging SSI,[7] lack of time to implement SSI or feeling constrained by curricula, and/or lack of support from administrators.

Lack of Confidence, Fear of Backlash, and Gaps in Knowledge

Lack of confidence and concerns about backlash related to teaching controversial SSI were two key themes in reflections on my experience teaching and offering PD to teachers. In my reflections on the PD sessions I delivered, I recalled that teachers were concerned about navigating challenging conversations or circumstances in their classrooms and feared caregiver backlash for introducing controversial topics (specifically, vaccines or masking mandates during COVID-19). That is, teachers expressed concern about implementing controversial SSI and their preparedness to respond to unexpected circumstances, which I also experienced as a classroom teacher.[8] Similarly, Hall and Woika (2018) identified that American teachers may fear teaching evolution due to concerns of inciting conflict. In the Canadian context, Asghar et al. (2007) explored pre-service teachers' perspectives on teaching evolution; they reported concerns related to their understanding of evolutionary science, pedagogical knowledge, and the religious beliefs of students and parents.

Concerns about subject-area/content knowledge may also affect teachers' implementation of SSI. I recall feeling nervous about introducing immunity and vaccines in my first year teaching Science 24 because I had limited background in this area, which constrained the types of activities I felt comfortable implementing in my classroom. Similarly, Bird et al. (2022) described how post-secondary biology educators in New Zealand felt they "lacked the expertise to discuss these topics [gender and sexuality] in depth and access useful resources that could be provided to students" (p. 233). McNeal et al. (2014) focused on American teachers' subject-area knowledge of climate change and found that, despite educators being generally knowledgeable, misunderstandings persisted. Further, teachers' knowledge and perceptions of climate change differed by political orientation (McNeal et al., 2014). In my reflections on the PD workshops I offered, participants did not describe concerns about subject area knowledge as a factor that influenced their participation; however, it is plausible that teachers who attended the sessions were interested in expanding their knowledge of vaccines or COVID-19. Furthermore, some discussion about the political climate in teachers' communities arose during the PD sessions. Similarly, in a survey exploring the experiences of Canadian and American social-studies and science teachers,

[7] Such as COVID-19 vaccines in 2021, when I first developed the PD sessions.

[8] I recall, in particular, an instance where I was unsure how to respond to a student who told me they were not vaccinated because their parents did not believe in vaccination. I was concerned about offending the student and their parents.

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Waddington et al. (2024) reported that teachers' approaches to teaching controversial issues were impacted by the political climate in which they worked. Future exploration of how teachers' political orientation and the political orientation of the broader school/community impact SSI implementation in Canadian classrooms could provide greater insight into the complex realities teachers face.

Not Enough Resources, Not Enough Time

Lack of resources and time to implement SSI was another theme in my reflections, particularly from the PD sessions I delivered, where teachers expressed difficulty finding quality resources on COVID-19 and COVID-19 vaccinations. This may have been because information was rapidly evolving during that period of *science-in-the-making* (Herman et al., 2022). Further, discussions with teachers highlighted that providing opportunities to explore nuanced SSI can be difficult in content-heavy courses, where they felt constrained by the knowledge outcomes they needed to cover. Similarly, the literature I reviewed critiqued current curriculum documents for underemphasizing SSI (Beatty et al., 2021; Field et al., 2023; Höttecke & Allchin, 2020; Kienhues et al., 2020; Zhao, 2019),[9] as was mentioned under Question 1. For example, Beatty et al. (2021) argue that current science education is "divorced from social issues" (p. 1) and too focused on scientific knowledge and methods. Similarly, Zhao (2019) suggests that:

> We may have placed too much emphasis on the instrumental purposes of STEM [Science, Technology, Engineering and Math] education, on its uses and functions for global competition, job security, and monetary gain, and not enough on learning the art of thinking and transferring such learning to students' social and personal lives. (p. 394)

When curricula continue to prioritize preparing future scientists and acquiring knowledge for the sake of innovation and economic competition over socio-environmental well-being, teachers may be limited in their ability to integrate SSI.

Will My Administration Back Me Up?

The last theme from my reflections was that some teachers may lack support from upper administration related to teaching controversial SSI. Teachers highlighted the importance of a supportive administrative team in their decision-making around whether or how they might include topics like COVID-19 vaccinations in their classrooms, particularly if they were concerned about caregiver or community backlash. Anecdotally, teachers may feel more confident in integrating these topics if they expect administrators to support them if a caregiver or community member questions what is happening in their classroom. Conversely, one participant described an instance where a superintendent explicitly instructed teachers not to discuss COVID-19 vaccines/mask mandates. Others have identified a lack of administrative support (e.g., Chen & Xiao, 2021) as a factor related to teachers' implementation of SSI.

Recommendations and Possible Solutions

Based on the reviewed literature, my reflections on teaching, and conversations with science educators, I propose four recommendations to address the challenges teachers face in

[9] The majority of these papers were written outside the Canadian context. Specifically, Beatty et al. (2021) and Zhao (2019) were writing from an American perspective. Höttecke & Allchin (2020) and Kienhues et al. (2020) were writing broadly but are situated at German and American institutions.

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implementing SSI. These include curriculum and assessment modifications, professional development, resource development/curation, and support from school administrators.

Modifications to Curriculum and Assessment

As described in previous sections, scholars have called for increased emphasis on SSI across science curricula (Duschl, 2020; Hodson, 2020; Lima & Nascimento, 2022; Viehmann et al., 2024). Shifting the focus of curricula would signal to teachers, students, and the public that understanding the social dimensions of science and engaging with SSI are core priorities of science education and could better realize the goal of preparing future citizens as competent outsiders with respect to science (Erduran, 2023; Feinstein & Waddington, 2020; Lima & Nascimento, 2022). This work needs to be done thoughtfully—not by adding more to curricula, but rather by deepening engagement with issues and allowing time for exploration and conversation. For example, Viehmann et al. (2024) argue that curricula should explicitly integrate risk evaluation and the translation of knowledge into action, so that students are better prepared to navigate decision-making related to future social and environmental challenges. In addition, opportunities to further integrate digital/media/information literacy in science curricula could be explored (Höttecke & Allchin, 2020). In the Canadian context, this could be taken up through the lens of science, technology and society (STS) and science, technology, society and environment (STSE), building on the work of Aikenhead (2006), Pedretti (2005), and Pedretti and Nazir (2011).[10] Other curricula could also be modified to emphasize the interdisciplinarity of SSI; for example, Viehmann et al. (2024) advocate for greater emphasis on SSI in social studies curricula. Interestingly, a recent analysis of how climate change was incorporated into Canadian curricula by Field et al. (2023) reported that in some provinces (e.g., Manitoba and Ontario), social studies curricula included more climate change expectations than science curricula. Future research in the Canadian context could explore how social studies, science, and other curriculum documents engage with other SSI, and where opportunities for cross-curricular exploration of SSI might exist.

Another consideration is whether science curricula should identify specific SSI, or whether teachers should have choice in the topics addressed. Lima and Nascimento (2022) recommend that the "decision on which socioscientific issues should be addressed … is collectively constructed by the teacher and the school community, based on concrete problems and concerns of the community" (p. 1377). However, leaving decisions of which SSI to address up to local groups could be logistically difficult for schools and teachers. From my perspective, teachers and students should have opportunities to select SSI relevant to their local context and interests, but some SSI should be required in science curricula. Specifically, globally spanning issues, particularly those where citizens are likely to encounter misinformation such as climate change and vaccinations, should be included as an invitation for students to begin to familiarize themselves with the scientific evidence related to these topics, practice digital and information literacy skills, and learn to engage respectfully with one another. Including such topics in curricula could help students become better informed and engaged future citizens (Morote & Hernández, 2022).

In advocating for curricular change, I also acknowledge that implementing new curricula is slow and cannot easily adapt to the realities of an ever-evolving information environment and yet-unforeseen SSI. Modifying assessment may be a more effective starting point for driving change. To Osborne and Pimentel (2022), assessment is "the most powerful and immediate lever"

[10] For more on the relationships between STSE, SSI, and "science-in-context" (Bencze et al., 2020, p. 825) approaches, see Bencze et al. (2020).

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(p. 5) in addressing scientific misinformation and better preparing students to evaluate SSI. Because assessments are high stakes, they serve as an important signal to both teachers and students (Osborne & Pimentel, 2022). A notable example of this shift is the *Programme for International Student Assessment* (PISA), which, for 2025, added a new competency which evaluates students' ability to "research and evaluate scientific information, claims and arguments in a variety of representations and contexts, and draw appropriate conclusions" (OECD, 2023, p. 23). Specifically, 15-year-olds who take this exam are now assessed on their ability to:

- Search, evaluate and communicate the relative merits of different sources of information (scientific, social, economic, and ethical) that may have significance or merit in arriving at decisions on science-related issues, and whether they support an argument or a solution;
- Distinguish among claims based on strong scientific evidence, expert vs. nonexpert, and opinion, and provide reasons for the distinction; and
- Critique standard flaws in science-related arguments using epistemic and procedural knowledge, e.g., poor assumptions, cause vs. correlation, faulty explanations, generalizations from limited data. (OECD, 2023, p. 23)

The inclusion of these competencies in PISA 2025 highlights the OECD's (2023) increased emphasis on evaluating skills necessary for navigating SSI and misinformation. Once data on the quality of such assessments is available, standardized assessments within Canada (i.e., provincial tests, where applicable[11]) could follow suit and adopt similar competencies.

Professional Development

Another recommendation emerging from my reflections is the need to train pre- and in-service science teachers. Areas of focus for PD programs may include deepening knowledge of key SSI (Morote & Hernández, 2022; Sullivan et al., 2014), developing teachers' epistemic cognition (Bellocchi et al., 2022) and understanding of the NoS (Farmer, 2020a, 2020b; Watson & Ragoub, 2025), developing information/digital literacy skills (Breakstone et al., 2018; Burron & Pegg, 2021; Ginosaur & Tal, 2018), and debunking skills (Schubatzky & Haagen-Schützenhöfer, 2022).

Deepening Teachers' Knowledge of Key SSI

As described previously in this paper, teachers' self-perceptions of confidence and expertise may impact their implementation of SSI (Bird et al., 2022; McNeal et al., 2014). Further, depending on their educational background and teaching experience, teachers may have limited background knowledge of specific SSI (Bird et al., 2022; McNeal et al., 2014), or the field may have advanced since they last formally studied it. Consequently, professional development should deepen teachers' subject area knowledge of specific SSI, especially in instances where prolific research is taking place (e.g., Artificial Intelligence [AI]) or where misinformation is common (e.g., vaccinations). Furthermore, PD topics should be driven by the teachers' needs and interests and aim to bolster teachers' confidence.[12] Thus, research in the Canadian context that explores teachers' perceptions of their own PD needs around SSI should drive the delivery of future opportunities.

[11] Not all provinces and territories within Canada have provincial assessments, and there is variability between provinces in testing systems (Cowley & MacPherson, 2022).

[12] An example of a future topic of interest could be generative AI, which PD programs could explore as an SSI while concurrently supporting teachers to build AI literacy (Estaiteyeh & Mindzak, 2025).

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Developing Teachers' Epistemic Cognition and Understanding of NoS

Epistemic cognition, while variously characterized, relates to an individual's ideas about knowledge and knowing (Bellocchi et al., 2022; Hofer, 2016). Greene et al. (2016) define epistemic cognition as "how people acquire, understand, justify, change, and use knowledge" (p. 1). In science education contexts, epistemic cognition has been linked to NoS, which describes the epistemological underpinnings of science (i.e. what science is and how knowledge is generated in science) (Greene et al., 2016; Höttecke & Allchin, 2020; Sinatra et al., 2014). Developing students' epistemic thinking and understanding of knowledge development in science was a primary focus of the literature I consulted during the scoping review (e.g., Barzilai & Chinn, 2020; Lombardi et al., 2016; Tseng, 2018), but teachers' epistemic cognition and understanding of NoS is also worthy of attention. Specifically, Bellocchi et al. (2022) highlight the importance of developing the epistemic cognition of science teachers, which is "a necessary step before pedagogies like those we have discussed [which aim to enhance students' epistemic cognition—including science inquiry, NoS, refutational texts, and developing communities of knowledge] can be widely embraced and understood" (p. 48). Similarly, Chinn et al. (2020) acknowledge that implementing discussions and activities in classrooms that prompt students' epistemic cognition may be challenging for teachers and recommend that teachers take opportunities to "slowly expand their repertoire" (p. 177) of approaches that support students to develop apt epistemic aims, criteria, and processes.

PD programs around NoS may be one way to enter these conversations and develop teachers' epistemic cognition. Indeed, direct and explicit instruction in NoS may be necessary to shape how teachers perceive science and teach the epistemic aspects of science (Farmer, 2020b; Watson & Ragoub, 2025). In the Canadian context, Watson and Ragoub (2025) highlight that secondary science teacher education programs may have limited inclusion of the nature, history, and philosophy of science. Thus, future PD programs in Canada could address these gaps. Drawing connections between SSI, such as COVID-19 and NoS, was not a key focus of the PD sessions I delivered between 2021 and 2024; however, moving forward, I would more explicitly focus on NoS and encourage teachers to do so in their classrooms as well.

Supporting Teachers' Information/Digital/ Media Literacy and Debunking Skills

Based on the literature and my reflections, PD on information/digital/media literacy could support science teachers in navigating SSI and responding to misinformation (Breakstone et al., 2018; Burron & Pegg, 2021; Schubatzky & Haagen-Schützenhöfer, 2022). For example, Burron and Pegg (2021) highlight that pre-service science teachers may be overconfident in their search behaviours and suggest that pre-service teacher instruction should include demonstrations of search string construction, using databases and search engines, and using curriculum documents in generating relevant search terms. Effective searching skills could help science teachers locate resources related to their teaching (Burron & Pegg, 2021) and could better prepare them to model these skills for their students.

In addition to support with information searching, teachers should also be able to access PD opportunities on how to evaluate online information and sources (Breakstone et al., 2018; Sinatra & Lombardi, 2020) and that explores how digital media impacts the communication (and miscommunication) of science (Allchin, 2023b; Schubatzky & Haagen-Schützenhöfer, 2022). For example, Schubatzky and Haagen-Schützenhöfer (2022) argue that teacher education should:

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> Not only address digital media or the digital landscape from an effectiveness point of view (e.g., how can we use digital media to enhance learning processes), but also thematize how digital media and growing digitality shape how we as consumers interact with science. (p. 16)

Teachers also need time to discuss how to respond to misinformation, for example, how they might prepare in advance to address common false claims (prebunking/inoculation)[13] or what they might do if misinformation arises unexpectedly (debunking) (Schubatzky & Haagen-Schützenhöfer, 2022).

Schubatzky and Haagen-Schützenhöfer (2022) provide an example of how PD programs on SSI can incorporate information/digital literacy skills and explicit instruction on pre- and debunking. In their exploratory case study, they developed an intervention for pre-service physics teachers that included both inoculation/prebunking and debunking around climate change misinformation. Their intervention improved the teachers' debunking skills and perceived knowledge about climate change. Further, these authors found that pre-service teachers "greatly overestimated their actual debunking skills before the intervention. However, through the intervention, the participants not only regained their initial level of self-efficacy, but they were also able to better self-evaluate their actual debunking skills" (p. 15). This case study, while preliminary, is significant because it highlights that teachers may overestimate their debunking skills, and that interventions for teachers that focus on pre/debunking in the context of SSI may positively impact teachers' knowledge about the SSI addressed (climate change, in this example) and ability to pre/debunk misinformation. Taken together, these studies suggest that future research is needed to explore how similar interventions impact teachers' classroom practice, and that investing in PD for science educators is warranted to better prepare teachers to evaluate information, identify misinformation, and model these skills for students (Breakstone et al., 2018; Burron & Pegg, 2021; Hodson, 2020; Schubatzky & Haagen-Schützenhöfer, 2022; Sinatra & Lombardi, 2020).

In reflecting on the PD sessions I offered, teachers responded well to integrating digital literacy skills into discussions and activities around SSI. As part of the sessions, I provided a list of common questions and misinformation around COVID-19 and COVID-19 vaccinations, encouraging teachers to look up information online to address one of these questions (or another of their choice) with a partner. Next, we discussed the strategies we used to locate and evaluate information and how we might respond to particular questions/claims in a classroom context. Anecdotally, this component of the PD session prompted rich and engaged discussion, sharing of teachers' personal experiences, and opportunities to compare and contrast different approaches to information searching and evaluation that could be modelled for students.

Bringing It All Together

Based on my reflections, future PD could support teachers to name, use, and model strategies to evaluate information (e.g., click restraint, lateral reading) and respond to misinformation (e.g., inoculation and debunking). Further, future PD could incorporate opportunities to connect information/digital/media instruction to SSI and deeper conversations around NoS (Breakstone et al., 2018; Schubatzky & Haagen-Schützenhöfer, 2022). Teachers could also be supported through

[13] Pre-bunking involves warning and preparing individuals for misinformation they are likely to encounter. Debunking involves refuting false information after it has been encountered (Cook et al., 2017).

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instruction on how to integrate their learning in the classroom context and by providing time to plan with colleagues to ensure coverage across grades and subjects (Breakstone et al., 2018).

Resource Development

Informed primarily by my reflections as a science educator and teacher educator, resource development and curation of pre-existing resources is another area where teachers could be better supported in engaging with SSI. Specifically, there should be funding and time to create and compile resources around emerging SSI. Investments from school districts, governments, or post-secondary institutions could support initiatives where teachers can collaborate and/or consult subject matter experts[14] to develop resources that could be shared widely. Furthermore, resources that are easily modifiable and applicable across a broad range of topics and grades (e.g., discussion frameworks, digital literacy tools) would be highly valuable for teachers (Burron & Pegg, 2021). Finally, sharing of resources, whether newly developed or collections of resources that have been curated and vetted by experienced educators, will be most powerful if accompanied by PD that explores how teachers could employ them in practice (Chinn et al., 2021).

Support from Administrators

The need for support from administrators emerged from my reflections on the PD sessions I offered, as well as my own classroom teaching experiences. Anecdotally, teachers may feel more confident teaching SSI when they can approach administrators with concerns or questions, engage in open dialogue, and know administrators will support them when caregiver or community concerns arise. Based on these reflections, the following recommendations are offered to administrators:

- consider and identify which SSI may be controversial or divisive in your community;
- be proactive in connecting with science teachers and department heads/subject area leads regarding how they approach these topics, and how these topics relate to science curricula (i.e., identify specific connections to grades, courses, units) and broader frameworks (e.g., STSE, Indigenous Ways of Knowing);
- draft potential scenarios in collaboration with teachers (e.g., caregiver concern over teaching content, student disagreement in class) and identify appropriate responses for teachers and administrators;
- collaborate to co-create clear and consistent expectations for students, caregivers, and community members with respect to bringing concerns forward; and
- prioritize opportunities for science teachers to attend PD programs that could support them to navigate these topics/issues.

Administrators, like teachers, cannot predict all circumstances they might encounter when integrating complex SSI in schools; however, some advance consideration and preparation may make navigating difficult situations easier.

[14] For example, the resources and PD sessions I offered were supported by the Centre for Mathematics, Science and Technology Education at the University of Alberta, with funding from Glyconet. Through this partnership, I was able to meet with experts including Dr. Dawn Bowdish (Immunologist and Canada Research Chair, Department of Pathology and Molecular Medicine, McMaster University) to support the development of resources for teachers around COVID-19 and vaccine hesitancy.

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Limitations

Themes reported in this article should be taken in the context of the following limitations. First, this work is a reflective commentary, and though it is informed by my experience conducting a scoping review, it does not have the methodological rigour of a scoping review. Further, the themes presented here were impacted (and limited) by the search terms used to locate papers. Thus, if alternate terms had been used (for example, to focus on barriers to SSI implementation or teachers' experiences), additional literature may have been located that contradicts or supports the themes identified herein. Finally, my reflections on the PD sessions and my teaching were based on anecdotes and personal experiences and do not represent the experiences of teachers across Canada. Future review studies that explore teachers' experiences related to the integration of SSI, like the work of Chen and Xiao (2021), and additional research on teachers' implementation of specific SSI (e.g., COVID-19, vaccines) within Canada could address some of these limitations.

Final Thoughts

Science education plays a crucial role in equipping students to navigate complex and polarizing SSI. However, it requires teachers to invite in the topics, conversations, and technologies that are sometimes eschewed from classrooms. To better prepare students to analyze SSI and identify science and health misinformation critically, I argued for increased curricular emphasis on SSI and an enhanced focus on information/digital/media literacy, intellectual virtues, and NoS ideas. Teachers face challenges integrating SSI in their classrooms. However, curriculum and assessment modifications, expanded PD programs, generation and sharing of resources, and expanded support from administrators could bolster teachers' efforts. This work is challenging but necessary to prepare future Canadians to engage with one another and with issues that impact us all.

Generative AI Disclosure Statement

During the preparation of this work, the author used Gemini (2.5 Flash) to decrease the word count of the paper. This involved pasting the drafted manuscript into Gemini and asking for sections that could be condensed to be indicated in bold. The AI output was then used to guide revision; text was not copied directly from Gemini. The author reviewed and edited all content in this document and takes full responsibility for the accuracy, originality, and integrity of the final manuscript. The manuscript reflects the author's own intellectual work.

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References

Aikenhead, G. (2006). *Science education for everyday life: Evidence-based practice.* Teachers College Press.

Alberta Education. (2014). *Science 24.* LearnAlberta. https://curriculum.learnalberta.ca/curriculum/en/pos/SCIGEN_14_24/SCN2288

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518–542. https://doi.org/10.1002/sce.20432

Allchin, D. (2023a). Marginalizing misinformation: The fast-and-frugal way. *Science Teacher*, *90*(5), 16–19. https://doi.org/10.1080/19434871.2023.12290278

Allchin, D. (2023b). Ten competencies for the science misinformation crisis. *Science Education, 107*(2), 261–274. https://doi.org/10.1002/sce.21746

Allchin, D., & Zemplén, G. Á. (2020). Finding the place of argumentation in science education: Epistemics and whole science. *Science Education, 104*(5), 907–933. https://doi.org/10.1002/sce.21589

American Chemistry Council. (2021, October 24). *Spotted in the headlines: Bad science.* https://www.americanchemistry.com/chemistry-in-america/news-trends/blog-post/2021/spotted-in-the-headlines-bad-science#_ftn1

American Library Association (ALA). (2006). *Information literacy standards for science and engineering/technology.* http://www.ala.org/acrl/standards/infolitscitech

Asghar, A., Wiles, J. R., & Alters, B. (2007). Canadian pre-service elementary teachers' conceptions of biological evolution and evolution education. *McGill Journal of Education / Revue des Sciences de l'éducation de McGill*, *42*(2), 189–209. https://mje.mcgill.ca/article/view/2219

Association of College and Research Libraries (ACRL). (2016). *Framework for information literacy for higher education*. http://www.ala.org/acrl/standards/ilframework

Azevedo, F., & Jost, J. T. (2021). The ideological basis of antiscientific attitudes: Effects of authoritarianism, conservatism, religiosity, social dominance, and system justification. *Group Processes & Intergroup Relations, 24*(4), 518–549. https://doi.org/10.1177/1368430221990104

Barzilai, S., & Chinn, C. A. (2020). A review of educational responses to the "post-truth" condition: Four lenses on "post-truth" problems. *Educational Psychologist, 55*(3), 107–119. https://doi.org/10.1080/00461520.2020.1786388

Barzilai, S., Mor-Hagani, S., Abed, F., Tal-Savir, D., Goldik, N., Talmon, I., & Davidow, O. (2023). Misinformation is contagious: Middle school students learn how to evaluate and share information responsibly through a digital game. *Computers & Education*, *202*, Article 104832. https://doi.org/10.1016/j.compedu.2023.104832

Beatty, A. E., Driessen, E. P., Gusler, T., Ewell, S., Grilliot, A., & Ballen, C. J. (2021). Teaching the tough topics: Fostering ideological awareness through the inclusion of socially impactful topics in introductory biology. *CBE–Life Sciences Education*, *20*(4), ar67. https://doi.org/10.1187/cbe.21-04-0100

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Beauvais, C. (2022). Fake news: Why do we believe it? *Joint Bone Spine*, *89*(4), Article 105371. https://doi.org/10.1016/j.jbspin.2022.105371

Bellocchi, A., Davis, J., Mills, R., Arthars, N., & Appanna, S. (2022). Preparing Australian science students for the post-truth world: Research-based pedagogies for developing students' epistemic cognition. *Teaching Science: The Journal of the Australian Science Teachers' Association*, *68*(4), 35–52. https://search.informit.org/doi/10.3316/

Belova, N., Krause, M., & Siemens, C. (2022). Students' strategies when dealing with science-based information in social media—A group discussion study. *Education Sciences*, *12*(9), 1–13. https://doi.org/10.3390/educsci12090603

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

Benjamin, K. A., & McLean, S. (2022). Change the medium, change the message: Creativity is key to battle misinformation. *Advances in Physiology Education*, *46*(2), 259–267. https://doi.org/10.1152/advan.00021.2021

Bilodeau, H., & Khalid, A. (2024). *The spread of misinformation: A multivariate analysis of the relationship between individual characteristics and fact-checking behaviours of Canadians* (Catalog no. 22-20-0001). Statistics Canada. https://www150.statcan.gc.ca/n1/pub/22-20-0001/222000012024003-eng.htm

Bird, R. J., Wibowo, E., Fitzgerald, R. P., Murray, K., Beres, M. A., & Girling, J. E. (2022). Teaching reproduction, gender and sexuality: Broad, multidisciplinary and nuanced. *Sex Education*, *22*(2), 228–241. https://doi.org/10.1080/14681811.2020.1845643

Boulianne, S., & Belland, S. (2022). Climate denial in Canada and the United States. *Canadian Review of Sociology/Revue Canadienne de Sociologie*, *59*(3), 369–394. https://doi.org/10.1111/cars.12388

Brante, E. W., & Strømsø, H. I. (2018). Sourcing in text comprehension: A review of interventions targeting sourcing skills. *Educational Psychology Review*, *30*(3), 773–799. https://doi.org/10.1007/s10648-017-9421-7

Breakstone, J., McGrew, S., Smith, M., Ortega, T., & Wineburg, S. (2018). Why we need a new approach to teaching digital literacy. *Phi Delta Kappan*, *99*(6), 27–32. https://doi.org/10.1177/0031721718762419

Bromme, R., & Goldman, S. R. (2014). The public's bounded understanding of science. *Educational Psychologist*, *49*(2), 59–69. https://doi.org/10.1080/00461520.2014.921572

Brown, C. (2026). Science education's responses to misinformation: A scoping review. *Studies in Science Education, 1–29.* https://doi.org/10.1080/03057267.2026.2654793

Burron, G., & Pegg, J. (2021). Elementary pre-service teachers' search, evaluation, and selection of online science education resources. *Journal of Science Education and Technology*, *30*(4), 471–483. https://doi.org/10.1007/s10956-020-09891-z

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Canadian Medical Association (CMA) & Abacus Data. (2025). *Canadian Medical Association 2025 health and media annual tracking survey: 2nd edition.* Canadian Medical Association. https://digitallibrary.cma.ca/link/digitallibrary761

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review*, *32*, Article 100377. https://doi.org/10.1016/j.edurev.2020.100377

Chinn, C. A., Barzilai, S., & Duncan, R. G. (2020). Disagreeing about how to know: The instructional value of explorations into knowing. *Educational Psychologist*, *55*(3), 167–180. https://doi.org/10.1080/00461520.2020.1786387

Chinn, C. A., Barzilai, S., & Duncan, R. G. (2021). Education for a "post-truth" world: New directions for research and practice. *Educational Researcher*, *50*(1), 51–60. https://doi.org/10.3102/0013189X20940683

Cook, J., Ellerton, P., & Kinkead, D. (2018). Deconstructing climate misinformation to identify reasoning errors. *Environmental Research Letters*, *13*(2), 024018. https://doi.org/10.1088/1748-9326/aaa49f

Cook, J., Lewandowsky, S., & Ecker, U. K. H. (2017). Neutralizing misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence. *PLOS ONE, 12*(5), e0175799. https://doi.org/10.1371/journal.pone.0175799

Cowley, P., & MacPherson, P. (2022). Testing Canadian K-12 students: Regional variability, room for improvement. *Fraser Institute.* https://www.fraserinstitute.org/studies/testing-canadian-k-12-students-regional-variability-room-improvement

Duschl, R. A. (2020). Practical reasoning and decision making in science: Struggles for truth. *Educational Psychologist*, *55*(3), 187–192. https://doi.org/10.1080/00461520.2020.1784735

Erduran, S. (2023). Social and institutional dimensions of science: The forgotten components of the science curriculum? *Science*, *381*(6659). https://doi.org/10.1126/science.adk1509

Estaiteyeh, M., & Mindzak, M. (2025). Building AI literacy in pre-service teacher education in Canada: A case study of two cohorts. *Journal of Teaching and Learning*, *19*(4). https://doi.org/10.22329/jtl.v19i4.10041

Estigarribia, L., Torrico Chalabe, J. K., Cisnero, K., Wajner, M., & García-Romano, L. (2022). Co-design of a teaching-learning sequence to address COVID-19 as a socio-scientific issue in an infodemic context. *Science & Education*, *31*(6), 1585–1627. https://doi.org/10.1007/s11191-022-00362-y

Farmer, S. (2020a). Science teachers' lack of understanding of the nature of science: Does it matter? Part 1. *School Science Review*, *101*(377), 58–63.

Farmer, S. (2020b). Science teachers' lack of understanding of the nature of science: Does it matter? Part 2. *School Science Review*, *102*(378), 72–76.

Feinstein, N. (2011). Salvaging science literacy. *Science Education*, *95*(1), 168–185. https://doi.org/10.1002/sce.20414

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Feinstein, N. W., Allen, S., & Jenkins, E. (2013). Outside the pipeline: Reimagining science education for nonscientists. *Science*, *340*(6130), 314–317. https://doi.org/10.1126/science.1230855

Feinstein, N. W., & Waddington, D.I. (2020). Individual truth judgments or purposeful, collective sensemaking? Rethinking science education's response to the post-truth era. *Educational Psychologist, 55*(3), 155–166. https://doi.org/10.1080/00461520.2020.1780130

Field, E., Spiropoulos, G., Nguyen, A. T., & Grewal, R. K. (2023). Climate change education within Canada's regional curricula: A systematic review of gaps and opportunities. *Canadian Journal of Educational Administration and Policy*, *202*, 155–184. https://doi.org/10.7202/1099989ar

Flener-Lovitt, C. (2014). Using the socioscientific context of climate change to teach chemical content and the nature of science. *Journal of Chemical Education*, *91*(10), 1587–1593. https://doi.org/10.1021/ed4006985

Ginosar, A., & Tal, T. (2018). Teaching journalistic texts in science classes: The importance of media literacy. *Journal of Science Education and Technology*, *27*(3), 205–214. https://doi.org/10.1007/s10956-017-9718-9

Gotlib, A., & Groenhout, R. (2022). Fractured epistemologies: Bioethics pedagogy meets science denialism. *Teaching Philosophy*, *45*(4), 447–476. https://doi.org/10.5840/teachphil2022426168

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016). An introduction to epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 1–15). Routledge.

Gu, C., & Feng, Y. (2022). Influence of public engagement with science on scientific information literacy during the COVID-19 pandemic: Empirical evidence from college students in China. *Science & Education*, *31*(3), 619–633. https://doi.org/10.1007/s11191-021-00261-8

Hall, G. E., & Woika, S. A. (2018). The ongoing challenges to evolution education: Schools, the law, and classroom instruction. *The American Biology Teacher*, *80*(2), 87–91. https://doi.org/10.1525/abt.2018.80.2.87

Hansson, S. O. (2017). Science denial as a form of pseudoscience. *Studies in History and Philosophy of Science Part A*, *63*, 39–47. https://doi.org/10.1016/j.shpsa.2017.05.002

Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education*, *31*(5), 1105–1139. https://doi.org/10.1007/s11191-021-00306-y

Herrick, I., Sinatra, G., & Lombardi, D. (2023). Is that plausible? *NSTA*. https://www.nsta.org/science-teacher/science-teacher-januaryfebruary-2023/plausible

Hodson, D. (2011). *Looking to the future: Building a curriculum for social activism.* Sense Publishers.

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

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

Hofer, B. K. (2016). Epistemic cognition as a psychological construct: Advancements and challenges. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 19–38). Routledge.

Hornsey, M. J., Finlayson, M., Chatwood, G., & Begeny, C. T. (2020). Donald Trump and vaccination: The effect of political identity, conspiracist ideation and presidential tweets on vaccine hesitancy. *Journal of Experimental Social Psychology*, *88*, Article 103947. https://doi.org/10.1016/j.jesp.2019.103947

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, *104*(4), 641–666. https://doi.org/10.1002/sce.21575

Jarman, R., & McClune, B. (2007). *Developing scientific literacy: Using news media in the classroom*. Open University Press.

Julien, H., & Barker, S. (2009). How high-school students find and evaluate scientific information: A basis for information literacy skills development. *Library & Information Science Research, 31*(1), 12–17. https://doi.org/10.1016.j.lisr.2008.10.008

Kalu-Mamji, H., Boyle, B., Chinn, C. A., & Duncan, R. G. (2024). Evaluating evidence in epistemically unfriendly environments: Strategies and exemplary practices for science instruction. In R. Lindgren, T. I. Asino, E. A. Kyza, C. K. Looi, D. T. Keifert, & E. Suárez (Eds.), *Proceedings of the 18th International Conference of the Learning Sciences (ICLS 2024)* (pp. 1486–1489). International Society of the Learning Sciences. https://doi.org/10.22318/icls2024.165282

Kemei, J., Tulli, M., Olanlesi-Aliu, A., Tunde-Byass, M., & Salami, B. (2023). Impact of the COVID-19 pandemic on Black communities in Canada. *International Journal of Environmental Research and Public Health*, *20*(2), 1580. https://doi.org/10.3390/ijerph20021580

Kienhues, D., Jucks, R., & Bromme, R. (2020). Sealing the gateways for post-truthism: Reestablishing the epistemic authority of science. *Educational Psychologist*, *55*(3), 144–154. https://doi.org/10.1080/00461520.2020.1784012

Klucevsek, K. (2017). The intersection of information and science literacy. *Communications in Information Literacy*, *11*(2), 354–365. https://doi.org/10.15760/comminfolit.2017.11.2.7

Koehler, D. J. (2016). Can journalistic "false balance" distort public perception of consensus in expert opinion? *Journal of Experimental Psychology: Applied, 22*(1), 24–38. https://doi.org/10.1037/xap0000073

LaMotte, S. (2021, October 12). *Synthetic chemical in consumer products linked to early death, study finds.* CNN. https://www.cnn.com/2021/10/12/health/plastic-chemical-early-death-wellness/index.html

Lapsley, D., & Chaloner, D. (2020). Post-truth and science identity: A virtue-based approach to science education. *Educational Psychologist*, *55*(3), 132–143. https://doi.org/10.1080/00461520.2020.1778480

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Lazer, D. M. J., Baum, M. A., Benkler, Y., Berinsky, A. J., Greenhill, K. M., Menczer, F., Metzger, M. J., Nyhan, B., Pennycook, G., Rothschild, D., Schudson, M., Sloman, S. A., Sunstein, C. R., Thorson, E. A., Watts, D. J., & Zittrain, J. L. (2018). The science of fake news. *Science*, *359*(6380), 1094–1096. https://doi.org/10.1126/science.aao2998

Lederman, N. G., & Lederman, J. S. (2014). Is the nature of science going, going, going, gone? *Journal of Science Teacher Education*, *25*(3), 235–238. https://doi.org/10.1007/s10972-014-9386-z

Lewandowsky, S., Ecker, U. K. H., & Cook, J. (2017). Beyond misinformation: Understanding and coping with the "post-truth" era. *Journal of Applied Research in Memory and Cognition*, *6*(4), 353–369. https://doi.org/10.1016/j.jarmac.2017.07.008

Lewandowsky, S., & Van Der Linden, S. (2021). Countering misinformation and fake news through inoculation and prebunking. *European Review of Social Psychology*, *32*(2), 348–384. https://doi.org/10.1080/10463283.2021.1876983

Lima, N. W., & Nascimento, M. M. (2022). Not only "why" but also "how" to trust science: Reshaping science education based on science studies for a better post-pandemic world. *Science & Education*, *31*(5), 1363–1382. https://doi.org/10.1007/s11191-021-00303-1

Lombard, F., Schneider, D. K., Merminod, M., & Weiss, L. (2020). Balancing emotion and reason to develop critical thinking about popularized neurosciences. *Science & Education*, *29*(5), 1139–1176. https://doi.org/10.1007/s11191-020-00154-2

Lombardi, D., Nussbaum, E. M., & Sinatra, G. M. (2016). Plausibility judgments in conceptual change and epistemic cognition. *Educational Psychologist*, *51*(1), 35–56. https://doi.org/10.1080/00461520.2015.1113134

Maia, P., Justi, R., & Santos, M. (2021). Aspects about science in the context of production and communication of knowledge of COVID-19. *Science & Education*, *30*(5), 1075–1098. https://doi.org/10.1007/s11191-021-00229-8

McIntyre, L. (2019). *The scientific attitude.* MIT Press.

McNeal, K. S., Walker, S. L., & Rutherford, D. (2014). Assessment of 6- to 20-grade educators' climate knowledge and perceptions: Results from the climate stewardship survey. *Journal of Geoscience Education*, *62*(4), 645–654. https://doi.org/10.5408/13-098.1

Morote, Á. F., & Hernández, M. (2022). What do school children know about climate change? A social sciences approach. *Social Sciences*, *11*(4), 179. https://doi.org/10.3390/socsci11040179

Organisation for Economic Co-operation and Development (OECD). (2023). PISA 2025 Science Framework (Draft). https://pisa-framework.oecd.org/science-2025/

Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt.* Bloomsbury.

Osborne, J., & Allchin, D. (2025). Science literacy in the twenty-first century: informed trust and the competent outsider. *International Journal of Science Education*, *47*(15–16), 2134–2155. https://doi.org/10.1080/09500693.2024.2331980

Osborne, J., & Pimentel, D. (2022). Science, misinformation, and the role of education. *Science, 378*(6617), 246–248. https://doi.org/10.1126/science.abq8093

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, *107*(3), 553–571. https://doi.org/10.1002/sce.21790

Pedretti, E. (2005). STSE education: Principles and practices. In S. Alsop, L. Bencze, & E. Pedretti (Eds.), *Analyzing exemplary science teaching: Theoretical lenses and a spectrum of possibilities for practice* (pp. 116–126). Open University Press.

Pedretti, E., & Nazir, Y. (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

Phippen, A., Bond, E., & Buck, E. (2021). Effective strategies for information literacy education: Combatting 'fake news' and empowering critical thinking. In D. Baker & L. Ellis (Eds.), *Future directions in digital information* (pp. 39–53). Elsevier. https://doi.org/10.1016/B978-0-12-822144-0.00003-3

Reid, G., & Norris, S. P. (2016). Scientific media education in the classroom and beyond: A research agenda for the next decade. *Cultural Studies of Science Education, 11*(1)*,* 147–166. https://doi.org/10.1007/s11422-015-9709-1

Scheibenzuber, C., Hofer, S., & Nistor, N. (2021). Designing for fake news literacy training: A problem-based undergraduate online course. *Computers in Human Behavior*, *121*, Article 106796. https://doi.org/https://doi.org/10.1016/j.chb.2021.106796

Scheufele, D. A., & Krause, N. M. (2019). Science audiences, misinformation, and fake news. *Proceedings of the National Academy of Sciences*, *116*(16), 7662–7669. https://doi.org/10.1073/pnas.1805871115

Schubatzky, T., & Haagen-Schützenhöfer, C. (2022). Debunking climate myths is easy—Is it really? An explorative case study with pre-service physics teachers. *Education Sciences*, *12*(8), 566. https://doi.org/10.3390/educsci12080566

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education, 104*(5), 873–894. https://doi.org/10.1002/sce.21581

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist*, *49*(2), 123–138. https://doi.org/10.1080/00461520.2014.916216

Sinatra, G. M., & Lombardi, D. (2020). Evaluating sources of scientific evidence and claims in the post-truth era may require reappraising plausibility judgments. *Educational Psychologist*, *55*(3), 120–131. https://doi.org/10.1080/00461520.2020.1730181

Statistics Canada. (2023, July 20). *Canadian Internet Use Survey, 2022*. https://www150.statcan.gc.ca/n1/daily-quotidien/230720/dq230720b-eng.htm

Stroupe, D., Suárez, E., & Scipio, D. (2024). Epistemic injustice and the "nature of science". *Journal of Research in Science Teaching*, 62(4), 901–941. https://doi.org/10.1002/tea.21988

Strudwicke, I. J., & Grant, W. J. (2020). #JunkScience: Investigating pseudoscience disinformation in the Russian Internet Research Agency tweets. *Public Understanding of Science*, *29*(5), 459–472. https://doi.org/10.1177/0963662520935071

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Sullivan, S. M. B., Ledley, T. S., Lynds, S. E., & Gold, A. U. (2014). Navigating climate science in the classroom: Teacher preparation, perceptions and practices. *Journal of Geoscience Education*, *62*(4), 550–559. https://doi.org/10.5408/12-304.1

Tabak, I. (2020). Post-truth GPS: Detour at truth, take the long route to useful knowledge. *Educational Psychologist*, *55*(3), 181–186. https://doi.org/10.1080/00461520.2020.1784734

Tseng, A. S. (2018). Students and evaluation of web-based misinformation about vaccination: Critical reading or passive acceptance of claims? *International Journal of Science Education, Part B: Communication and Public Engagement, 8*(3), 250–265. https://doi.org/10.1080/21548455.2018.1479800

Tseng, A. S., Bonilla, S., & MacPherson, A. (2021). Fighting "bad science" in the information age: The effects of an intervention to stimulate evaluation and critique of false scientific claims. *Journal of Research in Science Teaching*, *58*(8), 1152–1178. https://doi.org/10.1002/tea.21696

Valladares, L. (2022). Post-truth and education: STS vaccines to re-establish science in the public sphere. *Science & Education*, *31*(5), 1311–1337. https://doi.org/10.1007/s11191-021-00293-0

Vamanu, I., & Zak, E. (2022). Information source and content: Articulating two key concepts for information evaluation. *Information and Learning Sciences*, *123*(1–2), 65–79. https://doi.org/10.1108/ILS-09-2021-0084

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The use of socioscientific issues in science lessons: A scoping review. *Sustainability*, *16*(14), 5827. https://doi.org/10.3390/su16145827

Waddington, D. I., Maxwell, B., MacLean, T., McDonough, K., & Tavassoli, N. (2024). How free are classroom teachers? Understanding teacher academic freedom in the United States and Canada. *Teachers and Teaching*, *32*(1), 53–74. https://doi.org/10.1080/13540602.2024.2422859

Wardle, C., & Derakhshan, H. (2017). *Information disorder: Toward an interdisciplinary framework for research and policymaking* (Vol. 27, pp. 1–107). Council of Europe. https://rm.coe.int/information-disorder-report-november-2017/1680764666

Watson, E., & Ragoub, S. (2025). Considering the nature of science content knowledge and pedagogical content knowledge in Canadian science education programs: An environmental scan. *Journal of Teaching and Learning, 19*(3), 83–103. https://doi.org/10.22329/jtl.v19i2.8619

Wuyckens, G., Landry, N., & Fastrez, P. (2022). Untangling media literacy, information literacy, and digital literacy: A systematic meta-review of core concepts in media education. *Journal of Media Literacy Education*, *14*(1), 168–182. https://doi.org/10.23860/JMLE-2022-14-1-12

Zhao, G. (2019). STEM education in the age of "fake news": A John Stuart Mill perspective. *Philosophy of Education Yearbook*, *75,* 393–406. https://doi.org/10.47925/75.2019.393

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Low-Cost, Community-Driven Pedagogy and Canadian SSI Education: A Cross-Cultural Analysis

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Abstract

Socioscientific issues (SSI) in education help develop citizens capable of engaging with complex science-society challenges; yet from literature reviewed by the researchers, some Canadian teachers face persistent barriers in implementing SSI education in underserved settings. This paper examines how a low-cost, community-driven approach to teaching waste recycling to Nigerian pre-service teachers that was developed by the authors, might inform SSI pedagogy in Canadian rural, francophone, and Indigenous contexts. Our argument is built upon a review of selected Canadian SSI education literature (2010-2024) and a cross-cultural case analysis to discuss the transferability of the approach and its implications for advancing equity in selected education contexts in Canada.

Keywords: socioscientific issues, community-driven pedagogy, teacher education, Canadian science education, equity in education

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Low-Cost, Community-Driven Pedagogy and Canadian SSI Education: A Cross-Cultural Analysis

The integration of socioscientific issues (SSI) into education has emerged as a crucial pedagogical approach for preparing citizens to engage with complex interdisciplinary challenges at the intersection of science, technology, and society (Viehmann et al., 2024). SSI in education are often open-ended and unresolved (Sadler, 2011). Climate change, public health crises, biotechnology ethics, and technological justice represent archetypal SSI that require citizens capable of critical thinking, ethical reasoning, and evidence-based decision-making (Herman, 2018).

SSI in education shares roots with the Science, Technology, Society, and Environment (STSE) movement and other sociocultural movements (Chowdhury, 2016). However, the distinction is that SSI place an explicit focus on developing moral intelligence (integrity and moral decision) and social responsibility, without bifurcating science into process and moral imperatives (Bencze et al., 2020). Scientific literacy is described as the ability to understand, interpret, and apply scientific concepts and processes (Tyler, 2024), and SSI education is a key aspect of scientific literacy because it equips learners to apply scientific knowledge to complex ethical, environmental, and societal issues.

One of the key outcomes of SSI in education is to engage students in social action, thus "enabling young people to be part of the solution to society's problems rather than contributing to them" (Hodson, 2014, p. 68). Despite these benefits, emerging research reveals that many science teachers, both pre-service and in-service, struggle to navigate the pedagogical complexities of integrating SSI in their teaching (Chen & Xiao, 2021). Moving towards embedding action in teaching is complex and difficult for teachers as it is a radical change (Hodson, 2020). Action-focused SSI in education puts new demands on teachers, challenging deep-rooted assumptions and beliefs that school is traditionally founded on, such as the view of knowledge as fixed, the teacher as the sole authority, and learning as the passive absorption of information rather than active engagement with real-world problems (Chowdhury, 2016).

Studies have shown that while SSI in science education is promoted for its potential to connect science learning with real-world, ethical, and societal concerns, many teachers feel ill-equipped to implement such pedagogies effectively (Zhang & Hsu, 2025). For instance, Pedretti et al. (2008) noted that 64 secondary pre-service teachers at a large Canadian university lacked a clear understanding of how to integrate issue-based STSE teaching, a challenge related to SSI education, in classroom practice especially when dealing with interdisciplinary content. In-service teachers, while aware of the value of SSI, cite the lack of time, assessment frameworks, and confidence in addressing contentious or value-laden topics as key barriers (Chen & Xiao, 2021). The implementation of SSI pedagogy tends to be inconsistent and context-dependent, with few systemic supports for professional development (PD) and/or curriculum reform in British Columbia (BC) (Jellema, 2024).

Recent pedagogical approaches for SSI in education in other educational contexts, such as the study by Erhabor and Reis (2026) on low-cost, community-based participatory research using discarded or waste materials to foster recycling behaviours among university student teachers in Nigeria, offer promising models for localized, resource-sensitive approaches to SSI in education. Against this backdrop, this paper draws on a review of Canadian-related literature to (i) identify existing barriers to implementing SSI in education programs across the country, and (ii) examine how the approach of Erhabor and Reis (2026) might inform SSI in education in Canadian rural,

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francophone, and Indigenous contexts. In the next section, we will describe key aspects of this approach.

Community-Driven, Low-Cost SSI in Education Approach of Erhabor and Reis (2026)

Erhabor and Reis (2026) propose a community-driven, low-cost pedagogical approach to SSI education. The study was conducted at a federal university in Nigeria. Developed in a resource-constrained educational context, this approach demonstrates how SSI-aligned competencies can be cultivated by engaging pre-service teachers in low-cost, community-based problem-solving. It emphasizes the use of locally available materials, contextualized learning, and active student engagement in addressing real-world environmental and social challenges because the institution where this study was conducted faces resource constraints that limit access to specialized environmental laboratory equipment and dedicated recycling facilities for practical instruction (Erhabor & Reis, 2026). Although recycling is increasingly recognized as an important component of environmental sustainability and environmental education, opportunities for students to engage in practical recycling activities may remain limited in Nigerian institutions. For example, Ifegbesan (2010) found that 77.3% of school students surveyed in Ogun State reported having no opportunity to reuse or recycle items in their schools, indicating limited practical engagement with recycling. These contextual challenges made this specific university an appropriate setting for evaluating whether low-cost, locally sourced instructional materials could provide an affordable and practical alternative for improving students' recycling knowledge and supporting sustainability education.

Erhabor and Reis (2026) employed a quasi-experimental pre-test–post-test control-group design using two purposively selected first-year B.Ed. classes of pre-service teachers from the Faculty of Education during the 2022–2023 academic session. One intact class served as the experimental group while the other served as the control group. Participation was voluntary and only pre-service teachers who provided informed consent and completed both the pre-test and post-test were included in the final sample, resulting in 25 participants in each group (n = 50).

The experimental group consisted of pre-service teachers in Health Education, while the control group consisted of pre-service teachers in Human Kinetics. Both groups received instruction on the same recycling concepts and were assessed using identical pre-test and post-test instruments. The principal difference between the groups was the instructional approach. The experimental group received instruction through hands-on, participatory activities using low-cost and locally available discarded or waste materials, whereas the control group received the same recycling content through conventional lecture-based instruction.

The use of pre-testing enabled the assessment of participants' baseline knowledge and attitudes before the instructional intervention and helped to account for pre-existing differences between the groups. Both groups participated in the study within the same institutional setting and academic period and were exposed to the intervention over the same study period. However, because the groups were intact classes drawn from different academic areas, differences in disciplinary background, previous experiences, and student engagement could not be completely eliminated. These potential confounding factors are inherent limitations of the quasi-experimental design and should be considered when interpreting the findings.

In this Nigerian university context, the pre-service teachers in the experimental group used recycled materials to create learning aids that encouraged practical engagement with recycling behaviours (Erhabor & Reis, 2026). This participatory and action-oriented approach reflects the

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goals of SSI education and demonstrates a potentially useful approach for educational programs, particularly in underserved or resource-constrained contexts. The findings suggest that creativity, active participation, and local relevance can support meaningful engagement with SSI without requiring expensive infrastructure.

This approach of Erhabor and Reis (2026) is explicitly grounded in Vygotsky's (1978) sociocultural theory, which asserts that cognitive development is influenced by cultural and social factors and occurs through interaction with cultural tools and more knowledgeable others. Vygotsky emphasizes the role of social interaction in the development of mental abilities, e.g., speech and reasoning in children (McLeod, 2025). Informed by Vygotsky's (1978) theory, in the approach used by Erhabor and Reis (2026), recycled materials, recycling processes, and waste management practices function as cultural tools that mediate student learning; they are not merely objects, but artifacts imbued with cultural meanings and practical purposes. Final-year students served as peer mentors, scaffolding learning of first-year students by breaking down complex activities, offering timely feedback, and progressively reducing assistance as learners developed confidence and competence. They also encouraged the use of bilingual language especially with the use of visual aids with minimal text to bridge language gaps. Thus, first-year students were able to participate in tasks within their zone of proximal development that were slightly beyond their independent capabilities but achievable with peer guidance.

Hence, in this approach, knowledge is socially constructed through collaborative problem-solving, group work, and peer teaching, emphasizing co-construction rather than individual discovery. It reflects constructivist learning principles. Students actively constructed understanding by manipulating materials, testing hypotheses (e.g., determining optimal pulp-to-water ratios), and addressing problems such as waste management. Inquiry-based learning is central, as activities provoked questions such as "Why does aluminum compress more easily than plastic?" or "What happens to waste that isn't recycled?" and drove further investigation. This approach also employs scaffolded complexity, moving learners from concrete tasks, such as hands-on recycling, to more abstract analyses of waste flow systems, thereby, progressively deepening conceptual understanding. Majority of the materials used in this study were waste and recycled materials received from the community.

The use of this SSI in education approach by Erhabor and Reis (2026) demonstrated notable gains in the pre-service teachers' knowledge and practical capacities regarding environmental sustainability. Quantitatively, the experimental group exhibited a pre-intervention mean score of 6.0 out of 10, which increased to 8.84 post-intervention, representing a 47% improvement. The control group showed a smaller increase, from 5.96 to 8.36 (40%). Analysis of covariance (ANCOVA) confirmed the statistical significance of these gains, with $F = 4.171$ and $p = 0.047$ at the $\alpha = 0.05$ level. These results indicate that the use of community-based participatory approach of SSI education significantly enhanced knowledge of recycling processes, waste categorization, environmental impacts, and sustainable management strategies.

In this paper, we use the above-mentioned SSI in education approach of Erhabor and Reis (2026) as a conceptual lens for examining how SSI education is implemented in Canadian contexts, particularly in rural, Indigenous, and under-resourced settings where similar constraints and opportunities may exist. To enhance analytical clarity, this approach is operationalized through four interrelated components: contextual relevance, low-cost resource utilization, participatory learning, and community integration, which are described below.

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Contextual Relevance

This component emphasizes the alignment of SSI instruction with learners' immediate environmental, social, and cultural realities. Rather than relying on abstract or distant examples, teaching is grounded in locally meaningful issues. In this present study, it was used to examine how Canadian SSI education literature reflects rural environmental concerns, localized socioscientific challenges, and regional diversity across provinces. Erhabor and Reis's (2026) approach closely aligns with core SSI pedagogy principles. The intervention fosters interdisciplinary integration, blending chemistry (paper pulping), physics (mechanical advantage in can crushers), biology (decomposition processes), economics (analyzing recycling business models), and ethics (environmental responsibility). Students engage in scientific argumentation and reasoning as they justify design choices, evaluate trade-offs between recycling methods, and debate priorities in waste management. Moral and ethical dimensions are central, as activities prompt reflection on equity in pollution burdens, intergenerational resource responsibility, and consumption choices. Furthermore, the approach emphasizes action competence, explicitly moving students from knowledge acquisition to values-driven behaviors, exemplified through campus campaigns and peer-led initiatives for sustainability.

Low-Cost Resource Utilization

This component focuses on the use of affordable, accessible, and locally available materials to support teaching and learning of SSI, reducing dependence on expensive or standardized resources. Using this component as a conceptual lens helped assess the resource disparities across Canadian schools and feasibility of SSI implementation in under-resourced or remote areas, as evident in the SSI literature reviewed (Sadler, 2011; Rivard & Gueye, 2016). A major principle of effective SSI education is that it does not depend on expensive laboratory equipment or commercial teaching aids. Rather, materials that would otherwise be discarded can be transformed into powerful pedagogical tools, providing students with meaningful, hands-on learning experiences. For example, in Erhabor and Reis's (2026) study, student teachers creatively repurposed readily available items from their environment: old newspapers and wastepaper were transformed into recycled paper products; wooden scraps, nails, and discarded plastic tubing were used to construct can crushers; empty buckets, gloves, and weighing scales facilitated waste auditing exercises; and natural colorants alongside absorbent cloths served as processing materials. The pedagogical rationale for this approach lies in the direct engagement with 'waste-as-resource,' allowing learners to experience the circular economy concept in a tangible way rather than abstractly. From an SSI perspective, repurposing materials encourages students to grapple with socioscientific dimensions of sustainability. They negotiate competing values such as economic viability versus environmental responsibility, evaluate trade-offs between convenience and ecological impact, and develop systems thinking by tracing material flows within society. This approach not only fosters practical skills but also cultivates critical reflection on sustainable practices and decision-making.

Participatory and Inquiry-Based Learning

Environmental literacy develops most effectively through embodied experiences that involve doing, making, observing, and reflecting rather than learning through textbook instruction alone. In the workshops organized during Erhabor and Reis's (2026) study, pre-service teachers engaged in three core hands-on activities that included paper recycling, can crushing and waste watching exercise. During the Paper Recycling session, they shredded paper, prepared pulp, spread it on

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mesh screens, pressed excess water, and dried new sheets, navigating challenges of pulp consistency, coordinating production steps collaboratively, and engaging their senses to appreciate the labour intensity of recycling processes. In the Can Crusher Construction session, students designed and built simple mechanical devices from scrap materials, applying physics concepts such as leverage and compression to real-world environmental problems while quantifying space-saving impacts. The Waste Watcher exercise involved collecting, weighing, categorizing, and analyzing personal waste over several days, with data visualization making abstract concepts like waste generation rates tangible and prompting critical reflection on personal consumption patterns. These experiential learning cycles encompassing concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984), enhance understanding, retention, and emotional engagement beyond what lectures alone can achieve. This hands-on approach aligns with SSI pedagogy, which emphasizes personally meaningful problems requiring dialogue, discussion, and critical engagement (Macalalag et al., 2024), transforming waste management from an abstract issue into a lived reality that students can actively influence. This component promotes active student engagement through dialogue, investigation, and collaborative problem-solving around real-world SSI. We used this component to analyze the extent of student-centered approaches in Canadian classrooms and opportunities for critical thinking and decision-making as reflected in the Canadian SSI literature.

Community Integration

This component highlights the inclusion of community knowledge systems, including Indigenous and local perspectives, in the teaching and learning of SSI. It is particularly relevant for examining how and in what ways Canadian SSI education literature illustrates Indigenous education contexts, cultural responsiveness and integration of local and traditional knowledge systems. In Erhabor and Reis's (2026) study, pre-service teachers led campus-wide aluminum-can collection campaigns, conducted peer-led recycling demonstrations, performed waste audits of their own consumption, and collaborated on designing local solutions to identified waste challenges.

Thus, the above four components collectively served as an analytical conceptual lens for examining the Canadian literature to analyze the implementation of SSI education in Canada. They guided the identification of key challenges and opportunities across diverse contexts, including rural, Indigenous, francophone, and under-resourced educational settings that were reflected in the literature reviewed. This conceptual lens also supports the exploration of how adaptable, community-driven approaches can enhance the relevance and effectiveness of SSI pedagogy. Table 1 below summarizes these components and their application to Canadian SSI education contexts.

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Table 1

Conceptual Lens Based on Erhabor and Reis's (2026) SSI in Education Approach

Component	Description	Application to Canadian SSI Contexts	Expected Outcomes
Contextual Relevance	Learning is grounded in real-life, local socioscientific issues.	Supports learning in rural and Indigenous communities where local realities shape education.	Improved relevance of SSI content and deeper student engagement.
Low-Cost Resource Utilization	Emphasizes the use of locally available and affordable materials for teaching SSI.	Addresses resource limitations in under-resourced and remote schools across Canadian provinces and territories.	Increased accessibility and feasibility of implementation of SSI education.
Participatory and Inquiry-Based Learning	Encourages active student involvement in discussion, investigation, and decision-making with regards to SSI.	Enhances student-centered learning across diverse classrooms, including francophone and multicultural settings.	Development of critical thinking and problem-solving skills.
Community Integration	Incorporates community knowledge, including Indigenous and local perspectives into SSI learning.	Aligns with Indigenous education principles and promotes culturally responsive pedagogy	Strengthened cultural relevance and socially responsible decision-making.

Methodology

This study adopts an integrative review methodology (Torraco, 2016) to critically synthesize empirical, theoretical, and policy literature on the implementation of SSI education in Canada. An integrative review methodology is a comprehensive research approach that systematically synthesizes literature from diverse sources and methodologies to create new knowledge and frameworks of understanding about a particular phenomenon (Whittemore & Knafl, 2005). An integrative review is well suited for examining complex educational phenomena, as it allows for the inclusion of diverse research designs, including quantitative, qualitative, mixed-methods, and conceptual frameworks (Torraco, 2016; Whittemore & Knafl, 2005).

A comprehensive literature search was conducted across the following electronic databases and supplementary sources:

- Scopus
- Web of Science
- ERIC
- ProQuest Dissertations & Theses Global
- Google Scholar
- Government and institutional policy repositories

The search included peer-reviewed journal articles and dissertations published in English between 2010 and 2024. The search terms used were combinations of keywords such as:

- socio-scientific issues OR socioscientific issues
- science education OR science pedagogy
- teacher education OR pre-service teachers OR in-service teachers OR teacher preparation

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- Canada OR Canadian education
- curriculum OR instruction OR implementation OR pedagogical practices

Boolean operators (AND/OR) were used to ensure inclusivity and relevance of results. The inclusion criteria were:

- Population: Pre-service and in-service teachers in Canadian K-12 education (all K–12 levels were included).
- Concept: Socioscientific issues (SSI), science literacy, teacher education, curriculum design, instructional strategies.
- Context: Canada; studies conducted within Canadian provinces and territories.
- Types of Sources: Peer-reviewed articles, reports, policy and curriculum documents, theses (English-language sources only due to translation constraints).
- Time Frame: Publications between 2010 and 2024.

Although the review focuses on Canadian literature, selected international studies related to SSI and low-cost educational materials were included to provide comparative insights, broaden inclusion criteria and illustrate transferable pedagogical strategies relevant to SSI implementation across diverse contexts. Teacher education was deliberately included in this review because the capacity of teachers to implement SSI pedagogy is shaped during pre-service and in-service training. Understanding barriers in teacher preparation is therefore essential to explaining classroom-level implementation challenges.

The exclusion criteria were:

- Studies conducted outside Canada unless they provided comparative insights relevant to the Canadian context.
- Literature not explicitly addressing SSI.
- Articles that lacked full text or were inaccessible after attempts to retrieve them.

The data collected were recorded based on the following aspects:

- Author(s), year of publication
- Study location and context
- Type of study (empirical, theoretical, policy)
- Focus of the study (e.g., teacher training, classroom implementation)
- Key findings related to SSI pedagogy
- Identified challenges, supports, and recommendations

The data collected were organized into a summary table by using Critical Appraisal Skills Programme (CASP, 2024) to evaluate each study's aim, methodology, key findings, strengths, limitations, and relevance to SSI teaching. The CASP is a structured tool used to assess the quality, rigour, and relevance of research studies. In this study, CASP was used to assess the quality and rigour of the included studies as indicated in Table 2 below. The four-component conceptual lens based on Erhabor and Reis's (2026) approach guided the analysis of each study's contribution to SSI teaching.

Thematic Analysis

Each study was appraised for methodological rigour (sample size, study design, and data collection and analysis), relevance (applicability to SSI pedagogy and teacher preparation in Canada), and credibility (peer-reviewed status, citation impact, or policy significance). This review found

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studies in provinces such as Ontario, Saskatchewan, Nova Scotia, BC and Alberta, with limited or no empirical studies identified for other Canadian provinces and territories.

A thematic synthesis (Thomas & Harden, 2008) was applied to identify patterns, concepts, and insights across studies. This thematic synthesis was conducted manually following a systematic process of familiarization, line-by-line open coding, and iterative grouping of similar codes into descriptive and analytical themes. Codes were developed from key findings across studies and refined through constant comparison to ensure coherence and alignment with this study's objectives. In view of the above, the themes derived were from the conceptual lens through four interrelated components of Erhabor and Reis (2026), namely, contextual relevance, low-cost resource utilization, participatory learning, and community integration.

Table 2

CASP Table for Selected SSI Studies

Study	Aim	Methodology	Key Findings	Strengths	Limitations	Relevance to SSI Teaching
Aikenhead & Elliott (2010)	To explore the emergence of decolonizing and cross-cultural science education in Canada, particularly Saskatchewan	Qualitative, documentary case study drawing on curriculum documents, previous research, stakeholder consultations, community collaboration and curriculum implementation	Integrating Indigenous and Eurocentric ways of knowing can reduce alienation, strengthen cultural identity, improve engagement and achievement, and promote scientific literacy	Community-centered, theoretically grounded, and provides a practical curriculum model	Mainly descriptive; Saskatchewan-focused; limited experimental evidence	Supports SSI teaching through culturally responsive, place-based, dialogic learning that incorporates Indigenous knowledge, multiple perspectives, sustainability, social and ecological justice
Bartlett et al. (2012)	To explore co-learning journeys between Indigenous and Western science	Narrative & reflective; based on program development	"Two-Eyed Seeing" essential for co-learning; advisory councils sustain efforts	Deep cultural insight; long-term reflection	Not generalizable; lacks empirical measurement	Critical for integrating Indigenous knowledge in SSI contexts
Bayram-Jacobs et al. (2019)	To examine science teachers' Pedagogical Content Knowledge (PCK) development through SSI	Mixed methods; data from lesson prep, reflection forms, observation tables; PCK model-based analysis	Teachers developed stronger PCK components for SSI; single module can improve PCK	Multinational sample; robust PCK framework	Short-term study; self-reported data	Strong insight into effective teacher professionali-zation in SSI teaching

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	curriculum enactment					
Bencze (2010)	To investigate pre-service teachers' engagement with student-led science/tech projects	Qualitative case analysis during methods course	Design projects encouraged core pedagogical practices; helped overcome teaching anxiety	Practical, innovative entry into pedagogy	Focused on teacher candidates; no long-term follow-up	Relevant for SSI through empowerment and inquiry-based methods
Bossér et al. (2015)	To explore challenges in implementing SSI in classroom practices	Qualitative; video-recorded discussions with teachers; year-long study	Teachers became more student-centered but struggled to align with learning goals	Longitudinal design; in-depth teacher reflections	Small sample; limited generalizability	Highlights pedagogical tensions in SSI implementation
Boucher (2015)	To discuss French-language school equity	Policy report	Highlights linguistic challenges and strengths	Focused on minority language rights	Not empirical study	Supports inclusive SSI delivery in minority language contexts
Bryant & Walker (2024)	To explore how principals support middle leader learning	Qualitative case studies across 12 schools	Principal-designed structures foster leadership learning	Context-sensitive models; supports job-embedded learning	Qualitative scope	Offers structural insights for building SSI leadership capacity
Burek & Zeidler (2015)	To explore conservation through SSI in informal learning	Descriptive and conceptual analysis	SSI can motivate conservation and activism among learners	Connection to real-world issues	Not empirical; conceptual in nature	Supports SSI's transformative potential for environmental literacy
Chen & Xiao (2021)	To review perceptions and challenges in SSI teaching	Systematic review of 25 studies (2004-2019)	Teachers lack clear SSI strategies; need systemic support	Comprehensive synthesis; practical recommendations	Broad range of study quality	Identifies system-wide enablers for effective SSI integration
Corbett (2014)	To argue for geography of rural education in Canada	Theoretical & conceptual	Rural schools undervalued but resilient	Advocates spatial understanding in policy	Canada-specific; theoretical	Spatial perspectives important for localizing SSI in rural settings

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Forbes & Davis (2010)	To understand how pre-service teachers adapt curriculum for inquiry-based science	Quantitative methods; curriculum design analysis	Pre-service teachers can adapt materials; inquiry-orientation influenced by existing materials	Focus on curriculum use/adaptation	Pre-service focus; may not translate to in-service settings	Shows how curriculum adaptation can support SSI-like inquiry learning
Jellema (2024)	To investigate how a Learning Study approach supports teacher professional learning for SSI pedagogy in secondary science classrooms	Qualitative case study using iterative lesson design, video analysis, and teacher reflection within a Learning Study framework	Teachers' understanding of SSI deepened, particularly in linking content to values-based reasoning; iterative design enhanced pedagogical confidence	Rich qualitative data; longitudinal engagement with teachers; strong practitioner collaboration	Small sample size; limited to one provincial context	Demonstrates how sustained, collaborative lesson study can strengthen teachers' capacity to implement SSI in practice
Kim et al. (2017)	To critique use of Traditional Ecological Knowledge (TEK) in science education	Critical literature review	TEK often misrepresented as Indigenous knowledge; calls for distinction	Sharp conceptual analysis	May be contentious; lacks field data	Key to decolonizing SSI teaching frameworks
Lyon et al. (2022)	To validate a scale measuring School Implementation Leaderships (SILS)	Quantitative; survey of 441 teachers; factor analysis	SILS validated with 21-item scale across 7 factors	Psychometrically sound; wide sample	Focused on leadership, not SSI per se	Provides tools for measuring support systems in SSI implementation
Rivard & Gueye (2016)	To investigate literacy-enhanced science instruction via PD program	Mixed methods over 3 years; teachers & students	PD improved teacher beliefs/ practices; boosted student literacy	Longitudinal; mixed methods	Context-specific; high teacher mobility	Emphasizes PD in supporting SSI-aligned literacy strategies
Sadler (2011)	To introduce SSI as contexts for promoting key science learning outcomes	Conceptual chapter drawing on empirical studies	SSI promotes content understanding, epistemic insight, and socioscientific reasoning; requires explicit	Clear articulation of SSI learning outcomes; widely cited foundational work	No direct empirical data; general recommendations	Provides theoretical underpinning for SSI integration into science education programs

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			pedagogical design			
Sullivan et al. (2018)	To compare rural disadvantages in science education across 3 countries	Secondary data analysis (PISA)	Rural students face greater challenges, especially in Australia	Strong international comparison	Does not focus on SSI directly	Provides context for implementing SSI in underserved rural areas
Therrien et al. (2022)	To examine place-based learning in postgraduate resource courses	Reflective survey & analysis	Place-based methods are enriching but sometimes lack critical depth	Innovative in linking place and extraction	Narrow postgrad focus	Inform SSI through localized real-world engagement
Viehmann et al. (2024)	To map and synthesize research on SSI use in science education	Scoping review; 106 articles from 2013-2023	SSI focuses on environmental/ genetic issues; methods are mainly qualitative	Broad synthesis; covers pedagogy & tech tools	Some studies lack depth; review-level	Useful map of current SSI teaching practices

Findings

A cross-cultural comparative lens was applied by using Erhabor and Reis's (2026) low-cost, community-driven SSI approach that they used in Nigeria. The four components as discussed in Table 1, provided a critical conceptual lens to analyze studies and examine principles of resource use, community engagement, and action-based SSI learning in Canadian teacher education; and exploring scalability of SSI education for rural, francophone, and underserved schools. Key themes around SSI education in Canada included the following:

1. Pedagogical knowledge gaps and PD needs among teachers;
2. Resource inequities and curriculum integration challenges;
3. Assessment and evaluation practices;
4. Community engagement, cultural responsiveness, and sociocultural dynamics.

Pedagogical Knowledge Gaps and PD Needs Among Teachers

The literature reviewed reveals significant gaps in teachers' understanding of SSI pedagogy in selected Canadian provinces (Ontario and BC). Shakkouri's (2017) study of Ontario secondary science teachers found that teachers' experiences informed understandings of SSI in education, highlighting how personal and professional backgrounds shape pedagogical approaches. Similarly, a study by Jellema (2024) in BC revealed that teachers' understandings of SSI were value driven, suggesting that personal beliefs significantly influence how educators approach SSI implementation. This creates inconsistencies in delivery and effectiveness across classrooms. Jellema also observed a lack of PCK among Canadian science teachers. While educators recognize the value of controversial issues like climate change or genetic engineering, many default to traditional didactic approaches due to discomfort with open-ended discussions or fear of parental and/or community backlash especially in rural or conservative areas.

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In summary, a persistent challenge in SSI education is that teachers often lack clear strategies for facilitating open-ended discussions and may fear appearing biased or ideological (Bossér et al., 2015; Jellema, 2024). Erhabor and Reis's (2026) approach addresses this by providing concrete, structured activities that naturally scaffold student engagement with SSI. Hands-on tasks such as designing recycled paper products or constructing simple mechanical devices prompt meaningful questions (e.g., "Is recycling always environmentally beneficial?" or "Who should bear the cost of waste management?") while keeping the focus on materials and processes. This design reduces the pressure on teachers to deliver 'correct' answers of specific SSI, enabling students to explore, debate, and reason collaboratively within a guided, yet open-ended, learning environment.

However, for the aspect of PD need, a pan-Canadian review (Bencze, 2010) revealed that only about 23% of science teacher training programs explicitly address SSI pedagogy. Shakkouri (2017) reinforces this emphasis on SSI, noting that teacher education programs need to "better engage future teachers in citizenship education [SSI] in order to make educators more comfortable educating for citizenship in science" (p. ii). Jellema's (2024) study strengthens the claim that PD programs (for in-service teachers in this case) need design features that allow iterative lesson planning, community of practice, and classroom enactment (the learning study itself is offered as one remedy). This study reveals that despite curriculum redesign in BC, which emphasizes 21st-century competency-based skills through SSI, "many teachers are having difficulties realizing the mandate" (p. 58). This suggests fundamental gaps in teacher preparation and PD.

Resource Inequities and Curriculum Integration Challenges

Sadler (2011) stresses that SSI is intended to achieve broader science education goals (e.g., citizenship, reasoning), but also notes practical barriers when curricula are tightly packed and assessment and accountability systems do not reward debate, deliberation, or extended inquiry. Provincial inconsistencies in curriculum integration present further challenges to the effective implementation of SSI education across Canada. For instance, BC is seen as a leader in environmental and SSI education, whereas Alberta's economic ties to fossil fuels may inhibit open discussions on climate change (Yadav, 2025). BC's K–12 curriculum is concept-based and competency-driven, providing numerous opportunities for students to explore climate change topics across various subjects (Government of British Columbia, 2025). BC has embedded SSI into its curriculum through courses like *Science for Citizens 11*, which explicitly address real-world science applications and promote inquiry into social and environmental issues (British Columbia Ministry of Education, 2023). Whereas in Alberta, the integration of certain aspects of SSI education such as climate change education, is influenced by the province's strong economic ties to the fossil fuel industry (Yadav, 2025). Research by Enoch and Eaton (2021) indicates that industry-sponsored materials are present in educational resources, potentially shaping the narrative around energy production and environmental issues. This influence raises concerns about the objectivity of climate education and the preparedness of students to engage with environmental challenges critically. Moreover, the Council of Ministers of Education, Canada (CMEC) (2024) notes that significant disparities remain in access to culturally relevant and linguistically appropriate materials, particularly in French-language and remote schools, which further affects the quality and consistency of SSI delivery.

One example of this is evident in Sadler's (2011) study which underscored persistent disparities in SSI support between urban schools and those in rural, northern, and francophone communities across Canada. While urban schools often benefit from better infrastructure and

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access to educational materials, schools in more remote or minority-language settings face significant challenges. A study by Rivard and Gueye (2016) highlights that minority-language schools, particularly francophone institutions outside Quebec struggle with limited access to appropriate French-language educational materials, face difficulties in recruiting qualified science teachers, and often have scarce PD opportunities. These challenges are exacerbated in rural and northern regions, where schools often operate in isolation and lack the economies of scale enjoyed by larger urban institutions. Teachers in these settings frequently contend with heavier workloads and multi-grade classrooms, which further hinders the delivery of robust science education including SSI education. Moreover, testimony before the House of Commons Standing Committee on Official Languages in 2024 revealed that the shortage of qualified francophone teachers is particularly acute in rural areas and this can affect the teaching of SSI as limited qualified teachers can seriously influence the expertise in teaching SSI in schools (House of Commons of Canada, Standing Committee on Official Language, 2024).

Thus, a significant barrier for SSI education in rural, northern, francophone, and Indigenous schools is the limited access to expensive science equipment and culturally appropriate SSI materials (CMEC, 2024; Rivard & Gueye, 2016). Erhabor and Reis's (2026) approach illustrates that meaningful SSI learning hinges on resourcefulness rather than resource abundance. By leveraging inexpensive or freely available waste and recyclable materials, students can achieve learning outcomes comparable to or even exceeding those produced by conventional, high-cost interventions. Evidence from related international research further supports this principle. International scholars such as Angrist et al. (2022), Whipp (2021), Mann et al. (2021), Hernández-Barco et al. (2021), and Piassi et al. (2019) provide robust empirical and theoretical support for Erhabor and Reis's (2026) low-cost, community-driven approach. For example, Angrist et al. (2022) demonstrate that low-cost educational interventions, averaging just US$19.00 per student, could yield effects equivalent to tutoring programs costing US$2,500.00 for each student, underscoring the potential of creative, contextually grounded approaches in resource-limited settings in teaching science education.

In addition to curricular content overload, teachers frequently identify time constraints as a significant barrier to implementing SSI education while teaching science. As a result, SSI is often perceived as an additional component rather than an integral part of the curriculum, leading to its limited adoption in classroom settings. For example, the study by Krell et al. (2024) found that despite the recognized value of SSI in fostering scientific literacy, teachers often struggle to incorporate these issues due to time limitations. Similarly, Bossér et al. (2015) reported that teachers face considerable challenges when implementing SSI, including the difficulty of balancing student-centered teaching practices with curriculum demands. This study suggests that without adequate time and resources, teachers may find it challenging to facilitate meaningful discussions around SSI. Teachers reported that the pressure to cover extensive content for examinations leaves little room for SSI discussions, which are perceived as time-consuming and less directly linked to exam content.

Therefore, teachers often perceive SSI as peripheral 'add-ons' rather than integral components of the curriculum, which results in minimal implementation despite policy endorsements of SSI in education (Krell et al., 2024; Viehmann et al., 2024). Erhabor and Reis's (2026) low-cost educational approach addresses this by embedding SSI learning directly within existing subject areas. For example, chemistry concepts are explored through paper pulping reactions, physics principles through mechanical systems in can crushers, data literacy through

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waste audits, and communication skills through peer-led teaching. This interdisciplinary integration not only aligns with multiple curriculum outcomes simultaneously, but also enhances instructional efficiency, positioning SSI as a core rather than as an optional element of science education.

Sadler (2011) frames SSI as an approach aligned to broad curriculum goals such as 21st-century competencies, but also signals that uptake depends on policy emphasis, assessment regimes, and administrative support validating the subtheme that policy both enables and constrains SSI education. Canada's decentralized system creates both innovation opportunities and systemic inconsistencies for SSI education. Provinces like Ontario and BC support SSI through curriculum frameworks, but lack of national standards and uneven enforcement often result in fragmented implementation (Young et al., 2013).

Furthermore, effective implementation of SSI in educational settings is significantly influenced by school leadership (Lyon et al., 2022). Principals who actively support interdisciplinary learning and critical inquiry, foster environments conducive to SSI integration. However, many administrators may lack the necessary understanding or may be hesitant to engage with potentially controversial SSI topics (Chen & Xiao, 2021).

Shakkouri's (2017) research emphasizes that supportive administrators and colleagues allow for science to be linked to SSI education. However, this support is inconsistent across institutions. Recent research underscores the pivotal role of strategic implementation leadership in adopting new educational practices among public school teachers from elementary schools (Lyon et al., 2022). Such intentional design includes aligning school processes with educational agendas and providing both formal and informal support structures (Bryant & Walker, 2024). Conversely, a lack of administrative support can hinder SSI implementation. Without backing from school leadership, these challenges can become significant barriers to integrating SSI into the curriculum. Therefore, successful integration of SSI in schools is closely tied to the proactive involvement of school leaders. By fostering a supportive environment and providing necessary resources and structures, principals can facilitate the effective teaching of SSI, thereby enhancing students' critical thinking and engagement with real-world issues.

Thus, Erhabor and Reis's (2026) approach to training pre-service teachers on resourcefulness and leadership (as senior students act as mentors to their junior peers) can help build leadership qualities among pre-service teachers. The peer-facilitation approach employed in Erhabor and Reis's study directly addresses these constraints by enabling senior students to teach junior peers, effectively supporting multi-age learning environments and mitigating the impact of limited teaching staff. Additionally, the use of low-cost, locally sourced materials reduces reliance on external suppliers or specialized facilities, making meaningful SSI learning feasible in resource-constrained settings.

Assessment and Evaluation Practices

Teachers often lack appropriate rubrics and tools to assess SSI competencies such as ethical reasoning, the quality of argumentation, and civic engagement (Forbes & Davis, 2010; Viehmann et al., 2024). Forbes and Davis (2010) report that about 70% of Canadian pre-service teachers in their study expressed uncertainty in evaluating SSI learning outcomes, while an estimated 80% had no preparation for handling culturally diverse perspectives. The SSI education approach by Erhabor and Reis (2026), addresses this gap through alternative assessment strategies that capture deeper learning outcomes. Performance tasks, such as successfully producing recycled paper,

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demonstrate practical understanding of processes. Portfolios including photographs, reflection journals, and waste audit data provide evidence of sustained engagement and learning. Peer evaluation, in which students assess one another's teaching demonstrations, fosters accountability and critical feedback. Finally, observable behavior changes, such as active participation in campus sustainability campaigns, document the translation of knowledge into real-world action. Collectively, these assessment strategies extend beyond conventional tests, capture the full spectrum of cognitive, affective, and civic competencies that are central to SSI education.

Community Engagement, Cultural Responsiveness, and Sociocultural Dynamics

Effective integration of SSI in education is not only dependent on the classroom context but also deeply shaped by the broader community, including parental attitudes, local cultural values, and sociopolitical dynamics (Högström et al., 2024). For community engagement and sociocultural dynamics, schools do not operate in a vacuum; rather, they reflect and are shaped by the communities they serve (Bartlett et al., 2012). Studies suggest that parental beliefs play a significant role in shaping whether and how teachers adopt SSI. Parental pushback on controversial content can lead to teacher self-censorship or avoidance of certain topics, especially in politically conservative regions (Bayram-Jacobs et al., 2019). Bossér et al. (2015) reveal that teachers often adopt a neutral stance in the classroom to avoid controversy and perceptions of indoctrination. This approach, while aiming to sidestep potential conflicts, may inadvertently hinder the development of students' critical thinking and moral reasoning skills. In contrast, when schools actively engage families and communities in discussions around the purpose and value of SSI, they create more supportive environments for teachers to integrate SSI education into their teaching (Chen & Xiao, 2021).

Hence, it is essential to provide pre-service teachers with training that emphasizes the importance of facilitating balanced, evidence-based discussions on SSI along with strategies for building respectful partnership with parents and community. Such training should aim to equip educators with strategies to navigate controversial topics effectively and in a culturally responsive manner, fostering an environment where students can engage in critical inquiry without fear of bias or indoctrination.

Though Erhabor and Reis's (2026) approach does not explicitly incorporate Indigenous epistemologies, it's commitment to local contextualization provides a practical framework for respectful communal engagements. By centering on community-sourced materials and addressing place-based environmental problems, their approach creates opportunities to integrate diverse ways of knowing, making SSI education more culturally relevant and inclusive.

Discussion

The findings from this review of SSI education in Canadian science education through the analytical lens of Erhabor and Reis's (2026) study suggest the need for an approach that focuses on the use of low-cost, community-based educational materials and presents a practical and transformative method for addressing many of the challenges Canadian teachers face in integrating SSI education into their classrooms.

One of the core challenges in Canadian science classrooms is the lack of PCK to facilitate SSI learning (Bayram-Jacobs et al., 2019). Teachers often revert to traditional didactic methods due to discomfort with controversial topics and an absence of effective strategies to manage open-ended, values-laden discussions of SSI. Here, Erhabor and Reis's (2026) experiential approach

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using recycled, low-cost materials provides a critical pedagogical counterpoint. By engaging pre-service teachers in the design of locally meaningful learning tools such as environmental aids built from discarded plastic and local artifacts, this approach emphasizes learning by doing, reflection, and community engagement. It not only builds pedagogical confidence but also grounds abstract scientific concepts in tangible, socially relevant contexts. Canadian teacher education programs could benefit from adapting this approach, particularly in helping pre-service teachers practice SSI facilitation through hands-on, resource-sensitive projects that simulate controversial SSI in a safe learning environment.

While provinces like BC have embedded SSI into curricula, others lag behind due to resource disparities and rigid, content-heavy structures. The development of culturally responsive science curricula in Saskatchewan required collaboration with Indigenous communities, customized textbooks, professional learning for teachers, and the involvement of Elders and Knowledge Keepers, highlighting the importance of context-specific instructional resources for Indigenous science education (Aikenhead & Elliott, 2010). This situation mirrors that of under-resourced Nigerian classrooms, where Erhabor and Reis (2026) demonstrated that pedagogical integration of SSI does not require high-cost materials but rather creative engagement with community resources. This work underscores that effective SSI education can emerge from localized, culturally-grounded, and sustainability-driven activities. Canadian rural and underserved schools could adapt this principle by developing place-based SSI curricula using local environmental, social, or economic issues as entry points for example, fracking in Alberta, salmon depletion in BC, or water rights of First Nations communities.

Canadian educators often view SSI as an 'add-on' rather than integral to the curriculum due to time pressure and exam-oriented structures (Viehman et al., 2024). The use of low-cost educational material approach suggested by Erhabor and Reis (2026) offers a potential solution by embedding SSI learning into existing disciplinary structures through interdisciplinary project-based work. For instance, SSI education can be integrated with civic education and sustainability through collaborative projects on waste management. By aligning SSI content with already mandated learning objectives, this approach reduces redundancy while maximizing impact. Canadian schools could implement similar integrated projects where SSI themes intersect with core competencies like critical thinking, inquiry, and civic engagement, thus making SSI education more feasible within packed schedules of teachers.

Many Canadian pre-service teachers receive limited exposure to facilitating SSI education during field placements, in part due to mentor in-service teachers' unfamiliarity or discomfort with the approach (Burek & Zeidler, 2015). Erhabor and Reis (2026) address this issue by embedding SSI-oriented tasks directly into pre-service teacher practicum experiences via action research. In this case, the pre-service teachers were required to identify a local environmental problem, investigate it, design low-cost educational intervention, and evaluate its impact with the guidance of their senior pre-service teachers and mentor in-school teachers during practicum placements. This cycle fostered not only practical experience but also a mindset of reflection, inquiry, and agency. If adapted into Canadian teacher education programs, this approach could help bridge the theory-practice gap while building pre-service teachers' confidence in dealing with controversial and community-relevant SSI topics.

In Canada, sociocultural dynamics, especially in conservative or extractive industry-dependent rural communities, pose barriers to SSI integration (Sullivan et al., 2018; Therrien et al., 2022). Erhabor and Reis's (2026) approach directly engages these dynamics by framing

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educational projects around locally acknowledged problems, such as pollution or unsustainable waste practices. This contextualized engagement not only reduces resistance but also enhances relevance and community ownership. In terms of reducing resistance from parents and community ownership, the pre-service teachers were encouraged to source materials from their household and community and adopt such practices when teaching during their practicum.

Canada's francophone and remote schools suffer from limited SSI resources and linguistic diversity, similar to the challenges faced in multilingual Nigerian classrooms. Erhabor and Reis (2026) reflected the use of bilingual peer-teaching and visual aids with minimal text to bridge language gaps. This strategy could be valuable in Canadian francophone communities, where visual and oral storytelling, local languages, and culturally grounded metaphors could support inclusive SSI education. Importantly, this approach underscores the value of co-creating materials with learners, which increases cultural relevance and ownership.

The findings from Canadian studies underscore systemic and pedagogical barriers to SSI implementation, from inadequate teacher training to resource disparities and sociopolitical sensitivities. Erhabor and Reis's (2026) work offers a viable and inspiring counter-narrative demonstrating that SSI-aligned learning does not require financial excess but rather a pedagogical shift toward resourcefulness and community engagement. This approach, developed in a resource-limited Nigerian context, can inform Canadian science educators to not only become technically competent but also socially responsive and pedagogically creative. By embedding SSI into real-world, low-cost, and context-specific teaching practices, Canadian education systems can better support science teachers in developing learners who are critically literate, ethically engaged, and equipped to navigate the science-society interface. Hence, the scalability of Erhabor and Reis's (2026) low-cost approach in resource-constrained Canadian contexts, particularly in rural, northern, and francophone communities facing resource disparities seems promising.

Conclusion and Significance

The findings of this review demonstrate that while Canada has made important progress in embedding SSI within science education, significant barriers continue to hinder effective implementation of SSI in education. These barriers include uneven curriculum implementation across provinces, limited access to contextually relevant instructional resources, inadequate preparation of pre-service teachers, insufficient PCK and lack of appropriate SSI related PD among teachers, sociocultural sensitivities surrounding controversial issues, and persistent inequities affecting SSI education in rural, Indigenous, northern, and francophone communities. Collectively, these challenges suggest that successful SSI implementation requires more than curriculum reform; it demands pedagogical approaches that are practical, contextually responsive, and sustainable. Viewed through the analytical lens of Erhabor and Reis's (2026) low-cost, community-driven instructional framework, the reviewed evidence points to an alternative pathway for strengthening SSI education. Rather than relying primarily on expensive technologies or externally developed teaching resources, Erhabor and Reis's framework demonstrates how locally available materials, community knowledge, experiential learning, and collaborative problem-solving can be leveraged to create authentic and meaningful SSI learning experiences.

This review underscores the need to redesign teacher education, PD, and curriculum structures to enable effective SSI implementation in Canada. Drawing on the insights from Erhabor and Reis (2026), the authors recommend the integration of low-cost, community-oriented, and action-based educational practices as a pragmatic and scalable approach to preparing teachers,

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particularly in underserved areas. Equipping Canadian teachers to effectively integrate action-oriented SSI will require coordinated policy support, contextual responsiveness, and inclusive pedagogical innovation.

Generative AI Disclosure Statement

AI tools were used solely to support language editing, including grammar checking, sentence refinement, and the organization and arrangement of the manuscript. All substantive arguments, interpretations, analysis, and conclusions are the responsibility of the authors.

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References

Aikenhead, G. S., & Elliott, D. (2010). An emerging decolonizing science education in Canada. *Canadian Journal of Science, Mathematics and Technology Education*, *10*(4), 321–338. https://doi.org/10.1080/14926156.2010.524967

Angrist, N., Bergman, P., & Matsheng, M. (2022). Experimental evidence on learning using low-tech when school is out. *Nature Human Behaviour, 6*(2022), 941–950. https://doi.org/10.1038/s41562-022-01381-z

Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together Indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies and Sciences, 2*(4), 331–340. https://doi.org/10.1007/s13412-012-0086-8

Bayram-Jacobs, D., Henze, I., Evagorou, M., Shwartz, Y., Aschim, E. L., Alcaraz-Dominguez, S., Barajas, M., & Dagan, E. (2019). Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. *Journal of Research in Science Teaching, 56*(9), 1207–1233. https://doi.org/10.1002/tea.21550

Bencze, J. L. (2010). Promoting student-led science and technology projects in elementary teacher education: Entry into core pedagogical practices through technological design. *International Journal of Technology and Design Education, 20 (1)*, 43–62. https://doi.org/10.1007/s10798-008-9063-7

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

Bossér, U., Lundin, M., Lindahl, M., & Linder, C. (2015). Challenges faced by teachers implementing socio-scientific issues as core elements in their classroom practices. *European Journal of Science and Mathematics Education, 3*(2), 159–176. https://doi.org/10.30935/scimath/9429

Boucher, M. (2015). *Focus on the French-language school*. People for Education. https://peopleforeducation.ca/wp-content/uploads/2017/06/MWM-Focus-on-the-French-language-school-2015.pdf

British Columbia Ministry of Education. (2023). *Science curriculum: Science for citizens 11*. https://curriculum.gov.bc.ca/sites/curriculum.gov.bc.ca/files/curriculum/science/en_science_11_science-for-citizens.pdf

Bryant, D. A., & Walker, A. (2024). Principal-designed structures that enhance middle leaders' professional learning. *Educational Management Administration & Leadership*, *52*(2), 435–454. https://doi.org/10.1177/17411432221084154

Burek, K., & Zeidler, D. L. (2015). Seeing the forest for the trees! Conservation research from a socioscientific perspective. In D. L. Zeidler (Ed.), *STEM education: A deficit or transformative model?* (pp. 146–168). Sense Publishers.

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review, 32*, Article 100377. https://doi.org/10.1016/j.edurev.2021.100377

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Chowdhury, M. A. (2016). The integration of Science-Technology-Society/Science-Technology-Society-Environment and Socio-Scientific-Issues for effective science education and science teaching. *Electronic Journal of Science Education, 20*(5), 19–38. https://eric.ed.gov/?id=EJ1188220

Council of Ministers of Education, Canada. (2024). *Promoting equality of educational opportunity: Canada report for the UNESCO 10th Consultation of Member States on the Implementation of the Convention and Recommendation against Discrimination in Education, 2017–20*. Council of Ministers of Education, Canada. https://www.cmec.ca/Publications/Lists/Publications/Attachments/442/Promoting_Equality_of_Educational_Opportunity_June-14-2024_EN.pdf

Corbett, M. (2014). Toward a geography of rural education in Canada. *Canadian Journal of Education/Revue canadienne de l'éducation, 37*(3), 1–22.

Critical Appraisal Skills Programme (CASP). (2024). *CASP checklist: For systematic reviews*. https://casp-uk.net/casp-checklists/CASP-checklist-systematic-reviews-checklist-2024.pdf

Enoch, S., & Eaton, E. (2021). *Crude lessons: Fossil fuel industry influence in Saskatchewan classrooms*. Canadian Centre for Policy Alternatives. https://www.policyalternatives.ca/publications/reports/crude-lessons

Erhabor, N. I., & Reis, G. (2026). Low-cost educational materials and university student teachers' recycling knowledge and attitudes: A quasi-experimental study. *Education Sciences*, *16*(2), Article 325. https://doi.org/10.3390/educsci16020325

Forbes, C. T., & Davis, E. A. (2010). Curriculum design for inquiry: Preservice elementary teachers' mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching, 47*(7), 820–839. https://doi.org/10.1002/tea.20379

Government of British Columbia. (2025). *Climate change connections in the B.C. curriculum: Kindergarten–Grade 3*. https://www2.gov.bc.ca/assets/gov/environment/climate-change/climate-literacy/bc_climate_change_curriculum_k-3.pdf

Herman, B. C. (2018). Students' environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction. *Journal of Research in Science Teaching, 55*(4), 600–638. https://doi.org/10.1002/tea.21433

Hernández-Barco, M., Sánchez-Martín, J., Corbacho-Cuello, I., & Cañada-Cañada, F. (2021). Emotional performance of a low-cost eco-friendly project based learning methodology for science education: An approach in prospective teachers. *Sustainability*, *13*(6), 3385. https://doi.org/10.3390/su13063385

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

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Högström, P., Gericke, N., Wallin, J., & Bergman, E. (2024). Teaching socioscientific issues: A systematic review. *Science & Education, 34*(5), 3079–3122. https://doi.org/10.1007/s11191-024-00542-y

House of Commons of Canada, Standing Committee on Official Language. (2024, December 10). *Evidence presented to the House of Commons Standing Committee on Official Languages, Meeting No. 125, 44th Parliament, 1st Session*. House of Commons of Canada. https://publications.gc.ca/collections/collection_2024/parl/xc60-1/XC60-1-2-441-125-eng.pdf

Ifegbesan, A. (2010). Exploring secondary school students' understanding and practices of waste management in Ogun State, Nigeria. *International Journal of Environmental and Science Education, 5*(2), 201–215. https://eric.ed.gov/?id=EJ884419

Jellema, E. (2024). *Understanding secondary science teachers' beliefs through a learning study in the context of socioscientific issues* [Master's thesis, University of British Columbia]. https://doi.org/10.14288/1.0447603

Kim, E. A., Asghar, A., & Jordan, S. (2017). A critical review of Traditional Ecological Knowledge (TEK) in science education. *Canadian Journal of Science, Mathematics and Technology Education, 17*(3), 258–270. https://doi.org/10.1080/14926156.2017.1380866

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Krell, M., Garrecht, C., & Minkley, N. (2024). Preservice biology teachers' socioscientific argumentation: Analyzing structural and content complexity in the context of a mandatory COVID-19 vaccination. *International Journal of Science and Mathematics Education, 22*(1), 121–141. https://doi.org/10.1007/s10763-023-10364-z

Lyon, A. R., Corbin, C. M., Brown, E. C., Ehrhart, M. G., Locke, J., Davis, C., Picozzi, E., Aarons, G. A., & Cook, C. R. (2022). Leading the charge in the education sector: Development and validation of the School Implementation Leadership Scale (SILS). *Implementation Science, 17*, Article 48. https://doi.org/10.1186/s13012-022-01222-7

Macalalag, A. Z., Jr., Kaufmann, A., Van Meter, B., Ricketts, A., Liao, E., & Ialacci, G. (2024). Socioscientific issues: Promoting science teachers' pedagogy on social justice. *Disciplinary and Interdisciplinary Science Education Research, 6*(1), Article 28. https://doi.org/10.1186/s43031-024-00118-4

Mann, J., Gray, T., Truong, S., Sahlberg, P., Bentsen, P., Passy, R., Ho, S., Ward, K., & Cowper, R. (2021). A systematic review protocol to identify the key benefits and efficacy of nature-based learning in outdoor educational settings. *International Journal of Environmental Research and Public Health, 18*(3), Article 1199. https://doi.org/10.3390/ijerph18031199

McLeod, S. (2025). *Vygotsky's theory of cognitive development*. Retrieved January 5, 2026, from https://www.simplypsychology.org/vygotsky.html)

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

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Piassi, L. P. C., Reis, G., Maclure, R., Gomes, E. F., Santos, F. R., Oliveira, T. M., Pupo, S. C., Teixeira, T. S., Cruz, L. D. L., Rodrigues, M. C., & Santos, M. B. P. (2019). Science stand: A Brazilian activist science & technology outreach initiative. *Journal for Activist Science and Technology Education, 10*(1), 1–11. https://doi.org/10.33137/jaste.v10i1.32909

Rivard, L. P., & Gueye, N. R. (2016). Enhancing literacy practices in science classrooms through a professional development program for Canadian minority-language teachers. *International Journal of Science Education, 38*(7), 1150–1173. https://doi.org/10.1080/09500693.2016.1183267

Sadler, T. D. (2011). Situating socio-scientific issues in classrooms as a means of achieving goals of science education. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 1–9). Springer

Shakkouri, L. (2017). *Citizenship education: A platform to engage secondary school science students in socio-scientific issues* [Master's thesis, Ontario Institute for Studies in Education of the University of Toronto]. TSpace Repository. https://utoronto.scholaris.ca/server/api/core/bitstreams/bb603182-36fa-43d5-a8d6-4e1792b82d60/content

Sullivan, K., McConney, A., & Perry, L. B. (2018). A comparison of rural educational disadvantage in Australia, Canada, and New Zealand using OECD's PISA. *SAGE Open, 8*(4), Article 2158244018805791. https://doi.org/10.1177/2158244018805791

Therrien, A., Lépy, E., Boutet, J., Bouchard, K., & Keeling, A. (2022). Place-based education and extractive industries: Lessons from post-graduate courses in Canada and Fennoscandia. *The Extractive Industries and Society, 12*(1), Article 100989. https://doi.org/10.1016/j.exis.2022.100989

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology, 8*(1), Article 45. https://doi.org/10.1186/1471-2288-8-45

Torraco, R. J. (2016). Writing integrative literature reviews: Using the past and present to explore the future. *Human Resource Development Review, 15*(4), 404–428. https://doi.org/10.1177/1534484316671606

Tyler, B. (2024). *Scientific literacy*. Research Starters, EBSCO Research. https://www.ebsco.com/research-starters/education/scientific-literacy#full-article

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The use of socioscientific issues in science lessons: A scoping review. *Sustainability, 16*(14), 5827. https://doi.org/10.3390/su16145827

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

Whipp, J. (2021). *Using Existing educational tools to support and enhance environmental education: Utilizing ecoliterary texts, gamifying education, and integrating technology* [Master's thesis, Lakehead University].

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https://knowledgecommons.lakeheadu.ca/server/api/core/bitstreams/617c923c-6d28-4ab7-bdf9-ea31ab313f0e/content

Whittemore, R., & Knafl, K. (2005). The integrative review: Updated methodology. *Journal of Advanced Nursing, 52*(5), 546–553.

Yadav, A. (2025, March 14). Federal and provincial governments often too friendly with fossil fuel industry have allowed it to shape climate education in schools. *The Pointer*. https://thepointer.com/article/2025-03-14/federal-and-provincial-governments-often-too-friendly-with-fossil-fuel-industry-have-allowed-it-to-shape-climate-education-in-schools

Young, M., Muller, J., Lukosch, H., & Young, C. (2013). Knowledge, expertise and the professions. In M. Young & J. Muller (Eds.), *Knowledge, expertise and the professions* (pp.1–22). Routledge.

Zhang, W. X., & Hsu, Y. S. (2025). Professional development for socioscientific issue teaching: Exploring the discourse of in-service teachers in community activities through epistemic network analysis. *Research in Science Education*, *55*(4), 961–987. https://doi.org/10.1007/s11165-025-10237-1

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Participating in Socioscientific Issue-Oriented Citizen Science Investigations: Mapping the Digital Terrain

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Abstract

Participation in Citizen Science (CitSci) projects can deepen understandings of science and the socially embedded nature of its practices, thereby better understanding science and scientists and better contextualizing science claims and knowledge. This paper draws attention to the reciprocal relationship between a socioscientific issues (SSI) framework and CitSci projects. As part of a broader study of CitSci projects within and across Canada, we developed an SSI analysis framework to understand and interpret how online text resources describing Canadian CitiSci projects integrate SSI perspectives. Our analysis suggests that selected SSI components are underdeveloped in online resources on project websites, and that participant engagement in most projects focus mainly on data collection. This analysis highlights opportunities to further understand and overcome challenges that influence whether such projects are implemented in K–12 and to explore how they might contribute to society and science overall.

Keywords: Citizen Science (CitSci), scoping, socioscientific issues (SSI), SSI framework, public science literacy

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Participating in Socioscientific Issue-Oriented Citizen Science Investigations: Mapping the Digital Terrain

In times of increasing mis- and dis-information, which can lead to public mistrust of experts and disengagement from knowledge, science educators have a critical responsibility to support students' understanding of science knowledge production processes and contexts (Osborne et al., 2022). Issue-oriented and affectively-attuned pedagogies and practices that engage the whole learner in real-world contexts may also orient learner identities toward belonging, participation, and decolonization, rather than disengagement and polarization (Martusewicz et al., 2020; Poole, 2025; Schultz et al., 2022). In classrooms and beyond, Citizen Science (CitSci) projects may offer entry points and repair practices toward broader sociopolitical wellbeing for youth and adults.

Citizen science is a term used in a broad range of contexts (Eitzel et al., 2017), but it is generally understood to refer to projects which involve members of the general public, who are not experts in science, interacting with some aspects of real-world science. This participation may be through data collection and/or interactions with, and for, practicing scientists (Land-Zandstra et al., 2021). It may be known or identified through other terms such as participatory or community science, which can have nuanced differences (Hacking et al., 2024). Our broader research project on CitSci is partly motivated by issues related to the public's impoverished understanding of science knowledge, an issue identified before the pandemic (Funk et al., 2019; Kennedy & Hefferon, 2019); how science as a practice is conducted (Osborne et al., 2022); how science facts are hardened (i.e., how scientific claims come to be accepted as fact; Havstad, 2020); how CitSci may offer entry points to climate change education (Neves et al., 2024; Sperling & Bowen, 2025); and how we can create bridging between formal and informal science education for social wellbeing (Falk & Dierking, 2003). This paper draws attention to the reciprocal relationship between a socioscientific issues (SSI) framework (Zeidler & Sadler, 2023) and CitSci projects.

The importance and value of CitSci projects are now gaining broader recognition in Canadian society. In December 2023, the honour of Membership in the Order of Canada was granted to James M. Richards "for his long-time ecological stewardship … and for his contributions to ornithology as a citizen scientist" (Governor General of Canada, 2023). This was the second time this term was noted in the rationale for selection, the first going to a bird conservation biologist the year prior (Governor General of Canada, 2022). This marks increased recognition of citizen scientists' contributions to society (although we also note these awards play into the inaccurate stereotype that CitSci is primarily about bird watching). For over two decades, the Government of Canada has also provided opportunities for Canadians to participate in CitSci projects such as the Naturewatch[1], CitSci hub (now defunded), and Fluwatcher[2]. It may be that Canadian federal government acknowledgements of such projects and participants speak to the need for public participation in science knowledge production. This need stems both from diminished funding and the capacity of scientists to gather data and from the inherent value of such participation to democratic practices, as it can help the public understand the origins of knowledge and, by extension, decision-making (Herman et al., 2022). This is where CitSci begins to be in conversation with the SSI framework.

From these entry points of complex issues and public participation, our research team explores the landscape of Canadian CitSci, including the practices, contributions, and potential for

[1] Naturewatch: https://www.naturewatch.ca/.
[2] Fluwatcher: https://www.canada.ca/en/public-health/services/diseases/flu-influenza/fluwatcher.html.

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formal and informal (i.e., non-school based) science education. We use this opportunity to expand our understanding of CitSci from an SSI framework. SSI has its own histories, underpinnings, and intentionalities within science education, predominantly located in K–12 (Zeidler & Sadler, 2023). By examining Canadian CitSci projects through an SSI lens, we hope to better understand how those projects might contribute to and fulfill SSI educational objectives, and how an SSI framework may create more robust opportunities for CitSci participation, ultimately enhancing the potential for a more scientifically literate citizenry.

Theoretical Framing

An SSI framework represents both a pedagogical approach and a content orientation for science education. SSI are often viewed in formal education as involving "the deliberate use of scientific topics that require students to engage in dialogue, discussion, and debate" around controversial topics with "the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns" (Zeidler & Nichols, 2009, p. 49). These topics have personal meaning, with the overall goal of increasing personal science knowledge. As the complexity of our world is increasing, there are emerging conceptualizations of SSI as "open-ended social problems with substantive connections to science" (Smit et al., 2025, p. 1) with a vision of scientific literacy that encompasses 'real' situations that are scientific in nature but are influenced by other factors, such as social, political, and ethical issues. SSI offer the capacity for science learners and teachers to acknowledge a growing tension in science education. Goals are changing over time from information for knowledge's sake (content-oriented) toward the development of decision-making citizens, especially around anthropogenic impacts on ecosystems. SSI-based learning offers a shift from purely monitoring components or systems toward being open to issues and powerful outcomes that were not certain. This encourages stepping outside disciplinary silos and toward meaningful, multifaceted engagement (Cunningham & Tan, 2026; Smit et al., 2025).

Before and during the pandemic, both media and academia noted that public (mis)trust in and (mis)understandings of science came to the fore (Funk et al., 2019), especially with the spread of false or misleading information through social media (Mann & Hotez, 2025), and that this lack of trust contributes to science resistance, doubt, and denial (Sinatra, 2026). In their review of literature on trust in science, Herman et al. (2022) note that the public's trust in *science in general* has been higher than trust in *science-in-the-making*. Osborne and colleagues (2022, 2023) identify several factors that need to be better addressed in school settings to develop an improved public understanding of science and its practices. Arguing that the role of science education should be primarily to develop 'competent outsiders' (Feinstein, 2011; Osborne & Allchin, 2025; Sandoval et al., 2025), whose orientation is less toward 'judging the evidence' for themselves, Osborne and collaborators (2022, 2023) contend that science education in schools should work toward developing an understanding of three key concepts: enacted social practices of science communities; the criteria that establish scientific expertise; and the basics of critical digital media literacy. Osborne and Pimentel (2023) further suggest that the first two are necessary to gauge the veracity of knowledge statements made by 'experts', in part by understanding just what constitutes expertise in a particular scientific area. However, this raises the question of how these issues can be addressed in K–12 education, highlighting the need to better understand what role informal science education opportunities, such as participating in CitSci projects, might offer.

CitSci projects have been documented around the world for decades (Tsybulsky & Tal, 2025; Vohland et al., 2021). One of the most prominent and renowned is the project hub of the Cornell

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Lab of Ornithology[3], which endeavours to track 10,000 bird species with the input of hundreds of thousands of people, claiming public "support enables discovery of new knowledge, innovation of new technologies to reveal that knowledge, teaching to foster new leaders, inspiration to motivate change, and transforming science to action to make a difference on the ground" (Cornell Lab of Ornithology, 2019). CitSci projects can vary broadly in the practices in which their participants engage. Projects can involve participation on limited days and/or at limited locations (e.g., species counts such as Eagle Watch[4]); activities that one might engage in regularly (e.g., driving down roads and reporting carcasses via the Canadian Wildlife Health Cooperative[5]); recording data while participating in recreational everyday pursuits (e.g., RinkWatch[6], which collects information on when one starts building a backyard rink and when it is ready for use); transcribing information from historical records provided by researchers into a database (e.g., with Notes from Nature[7]); or examining astronomical photographs from public archives to note and report particular astronomical events (e.g., the Planet Hunters TESS project[8]). Regardless, projects like these offer science literacy learning opportunities across spaces, demographics, and skill sets.

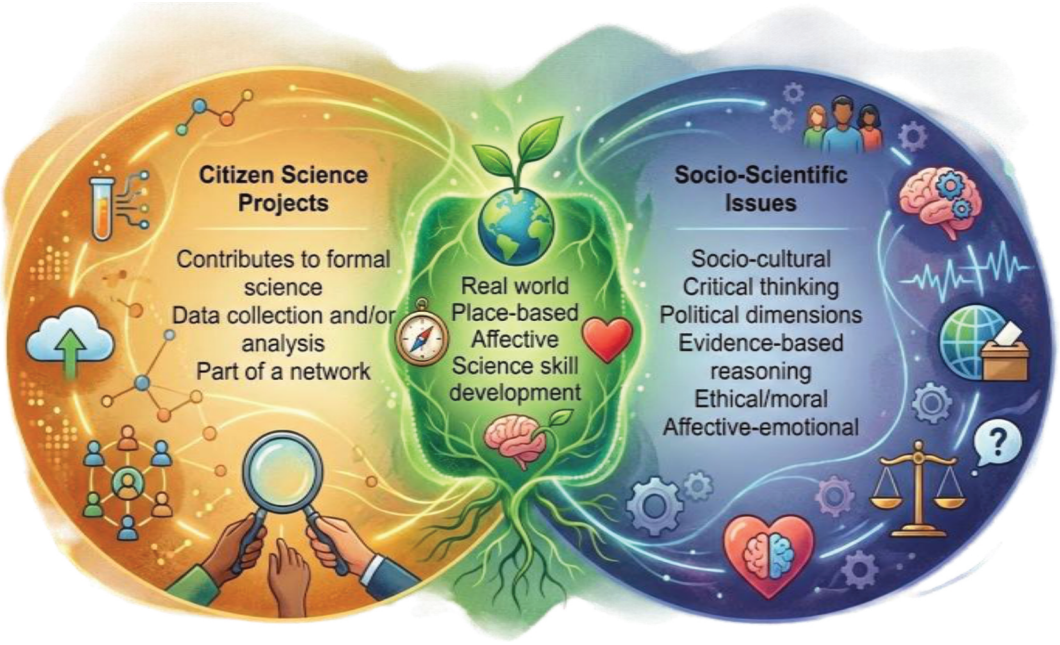
Some core benefits and learning opportunities for science literacy occur at the intersection of these two approaches, yet some aspects of SSI education diverge from CitSci. The core distinctions may be noted between knowledge production and sociopolitical complexity. For clarity, CitSci projects offer a method for the public to participate in real science and contribute to knowledge production. Such projects require a combination of technical, data-oriented, and/or direct connection to real-world science activities, while an SSI framework likely does not (Campos & Brito, 2024; Finger et al., 2023). SSI offer a conceptual framework that often requires explicit engagement in, and decision-making about, the sociopolitical dimensions of an issue, understanding of stakeholder interests and power dynamics, as well as inviting controversy, all of which are often underrepresented in CitSci project discourses (Högström et al., 2024; Pedretti & Nazir, 2011; Zeidler, 2014). Figure 1 identifies those constructs to which we are most attuned; the overlapping aspects being real world connections, connections to place, an affective aspect for the participant, and the development of science skills through participation. Of note, the blurry areas outside the circles are meant to demonstrate the fluid/less (un)defined spaces of each, and that each space is in constant dialogue with other spaces in flux, such as science knowledge, social norms, technology, politics, ecology, and so on.

[3] Cornell Lab of Ornithology: https://www.birds.cornell.edu/home/.
[4] Eagle Watch: https://eaglewatch.ca.
[5] Canadian Wildlife Health Cooperative: https://cwhc.wildlifesubmissions.org/.
[6] RinkWatch: RinkWatch.org.
[7] Notes from Nature: Digitizing Biological Collections in Canada: https://www.zooniverse.org/projects/md68135/notes-from-nature-digitizing-biological-collections-in-canada.
[8] Planet Hunters Transiting Exoplanet Survey Satellite (TESS). https://www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess.

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Figure 1

Conceptualizing Overlapping Aspects of SSI and CitSci



Note. The figure emphasizes the potential overlapping aspects of SSI approaches and CitSci projects. It was developed using Google AI based on an author-created figure for enhanced design purposes only.

In K–12 education, using SSI as an approach to support students' learning about science has considerable traction (Zeidler & Newton, 2017). Topics identified as being SSI often involve complex real-world societal concerns with social and cultural component interactions. These problems often have socio- and/or eco-ethical considerations. Examples of SSI include anthropogenic climate change, water fluoridation, vaccinations, plastics pollution, stem cell research, genetically modified organisms, and coastal erosion. Students examining these issues through an SSI lens are expected to integrate emergent scientific understanding and reasoning with social, economic, and political factors and actors (Högström et al., 2024). SSI frameworks encourage critical, multidimensional, and systems thinking, as well as consideration of sustainability implications.

Similarly, it has been suggested that engaging the general public with CitSci projects may help develop understandings of SSI in a productive and action-oriented way (Campos & Brito, 2024), and, in general, many (if not all) CitSci projects could be viewed through an SSI lens. However, much of the existing literature on SSI focuses on how to engage K–12 students–not adults–with those topics, even if such participation by adults would contribute to their development as "competent outsiders" (Osborne & Pimentel, 2023, p. 553). Further, there are connections between this research and the concept of Functional Science Literacy (Zeidler, 2014), which ideally concerns how citizenry is informed and develops capacity for more than technical understandings about science in order to make well-informed, evidence-based decisions about SSI. We note similarities in school science literacy goals and the science literacy goals intended for the general public.

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Using SSI approaches in classrooms has been found to generate enthusiasm, motivation, and interest in science (Neves et al., 2024; Zeidler & Kahn, 2014). A little-recognized component of being oriented toward SSI (noted in teachers selecting curriculum topics) is the way in which SSI may mobilize passion (Hancock et al., 2019), and this may help explain why individuals voluntarily participate in CitSci projects.

There is some internal tension within the field of CitSci. One variant of CitSci is known as community science. New research is helping to understand what, and how, distinctions may be made between and among citizen and community science (Hacking et al., 2024). CitSci is directly linked to many aspects of formal scientific investigation—irrespective of geographic boundaries—and community science projects are often locally based and are often intended to address local issues. The outcomes of such projects often influence local events and, unlike traditional CitSci projects, infrequently contribute to published scientific, academic literature. From an inclusivity standpoint, however, the label of community science may be perceived as more welcoming, as it destabilizes institutionalized or formal notions of citizenship and the attendant embodiments and representations as a prerequisite for participation (Cooper et al., 2021). Or, more succinctly, all persons in Canada are welcome to participate, regardless of formal citizenship status, which may not be clear from the label of CitSci (which, we note, does not limit participation by citizenship status). In fact, participatory science has become a more commonly used umbrella term within the field itself (Shirk, 2024). Additionally, in an increasingly complex world that competes for teacher and learner time and attention, research indicates that real-world, authentic and place-based learning, as offered by community science, enhances both the experiences and outcomes for all involved (Yemini et al., 2023). For the purposes of this study, all projects with opportunities for data collection (and in some cases beyond that) are included and listed under the label of CitSci.

In a meta-analysis of 157 CitSci projects globally, encompassing over 150,000 participants, Waugh et al. (2023) examined participant identities, demographic representation, and access to participation in CitSci projects. After narrowing their project to CitSci participants in North America, they reported that participants were disproportionately female, white, and educated (i.e., post-secondary). However, less than 8% of CitSci papers in the full dataset reported demographic data, suggesting a need for more studies to provide such information (Waugh et al., 2023). Understanding *who* may participate is especially important for understanding why individuals do or do not participate, which may support CitSci projects in providing more opportunities for engagement.

A recent typology of CitSci projects suggested "five mutually exclusive types" (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018, p. 30): investigation, virtual, conservation, action, and education. Additionally, our recent research has led us to suggest an additional, sixth typology to consider: Makers (Sperling & Bowen, 2025). The *Maker* typology emerged through our observations that certain CitSci projects invite participants to create, tinker, or enhance a physical and/or digital aspect of an entity to gather and document data, such as backyard rink-making (e.g., RinkWatch) or air quality testing with homemade kits (e.g., Agroclimate Impact Reporter[9]). However, in establishing that sixth typology, we also noted that the CitSci typology currently has no designation or recognition of SSI. This is perhaps unsurprising, given that the CitSci focus population is usually adults, while SSI research and

[9] Agroclimate Impact Reporter (AIR): https://agriculture.canada.ca/en/agricultural-production/weather/agroclimate-impact-reporter.

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practice is often oriented toward K–12 education (Viehmann et al., 2024). A recent systematic literature review by Solé et al. (2024) highlighted four different profiles of student participation in CitSci projects, but it did not report on the roles or learning outcomes in relation to SSI. This perceived dissonance between the age range of participants and formal/informal learning spaces led to this current research, in which we examined CitSci projects through an SSI lens. In this way, we are adopting the perspective that formal science education goals of learning about science and (potentially) its practices may emerge from participation in CitSci projects.

Indeed, much research examines the impact of CitSci as sites of knowledge production in formal science. We note a lack of research on the impacts of CitSci participation on participants' educational outcomes (Finger et al., 2023). To address this apparent lack of connection in the research literature on CitSci participation and the SSI-based formal education, we pose the following research questions:

(i) How might we assess existing CitSci projects in Canada through an SSI framework?
(ii) What are the possibilities and potentials of understanding CitSci through an SSI lens?
(iii) How might these outcomes be applied to K–12 education?

Methodology

Overview of Methodology

This project builds on our intention to expand knowledge of CitSci across Canada and apply a socioscientific framework to these projects. It is a mixed-methods research project, building off our case study of one long-range CitSci project that intersects backyard rink-making with climate change data analysis (Sperling & Bowen, 2025). Over the last year, we have conducted a scoping review (Arksey & O'Malley, 2005; Pham et al., 2014) of Canadian CitSci projects, defined in this study as projects run in Canada by Canadian institutions or organizations. To this point, we have identified over 100 such projects, 20 of which were used for this SSI analysis. Projects were selected for the scoping review through a few starting points: researcher prior knowledge, internet searches for keywords such as Canadian AND citizen OR community science, as well as using existing databases such as SciStarter[10] and the Government of Canada CitSci Portal[11]. As part of the analysis, we developed a schema to categorize projects in our database in relation to their SSI alignment(s) and clarify which science practices/SSI skill development would likely emerge from participation in each project.

For our analysis for this paper, we used a modified Interaction Analysis approach (Jordan & Henderson, 1995) combined with discourse analysis (Van Dijk, 2001), with a focus on the affective components of the text that might relate to potential participants' *passions*[12] as well as their sense of agency development. For each CitSci project, we independently viewed and annotated the data source(s) and framed individual assertions from those using both notes and scoring rubrics. In joint sessions, we collectively examined these individual assertions for each CitSci project, critiqued each perspective, and (re-)examined the database for confirming or disconfirming evidence, which we used to re-frame the collective assertions. Our final joint claims come from many such iterations of this process. To complement our qualitative analysis, we also

[10] SciStarter: https://scistarter.org/.
[11] Government of Canada Citizen Science Portal: https://science.gc.ca/site/science/en/citizen-science-portal.
[12] *Passion* can be defined as "a strong inclination toward an activity that people like, find important, and in which they invest time and energy" (Vallerand, 2008; p. 1).

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engaged in a quantitative analysis approach to develop our understanding of cross-relationships for each aspect of the overlap framework (see Figure 1) and the degree to which it is perceived to be enacted using a scoring schema.

Our research team consisted of two primary co-investigators (the co-authors) and four graduate student research assistants over two years, each possessing divergent backgrounds in science and teaching experience. We discussed and highlighted our differing and overlapping positionalities as researchers, teachers, and humans, and how these might entangle with the analysis. We noted potential biases along the identity spectra of gender, age, ability, geographic locations, and our pedagogical and disciplinary preferences. Through the fall of 2025, two research assistants, both with practical experience as classroom teachers (one elementary, one secondary), supported the authors with coding and analysis of the projects in our national database with specific attention to SSI. As a team, we scored each project based on our SSI sub-scales (described in detail below), with regard to both its relevance and potential for classroom teaching. Each of us used publicly available information for 20[13] projects in our database to evaluate their potential as a way to learn about SSI. We held regular virtual team meetings to discuss findings from our analyses of CitSci projects for potential classroom implementation. When Interaction Analysis draws on multiple interpretative perspectives, it is said to have greater 'ecological validity' (Jordan & Henderson, 1995), thereby leading to a broader and more nuanced interpretation of the data set with greater credibility. This, in turn, establishes an internal validity that reflects an "isomorphism between constructed realities of respondents and the reconstructions attributed to them" (Guba & Lincoln, 1989, p. 237), or, in other words, an assurance that there is a match between the constructed realities of the CitSci projects and those attributed to them through the analytic process.

Coding/Scoring CitSci Projects

Using our knowledge and expertise, along with emergent research on SSI and CitSci, we developed and applied the framework for analysis (described below). We needed to develop this analysis framework because this project engages with a task that has not, as far as we could find, been reported in SSI literature, namely, determining the degree to which learning environments unintentionally and implicitly encourage SSI learning. In this case the tacit learning about SSI arising from engaging in CitSci projects as a participant. This analysis framework consisted of six categories to review aspects of individual active CitSci projects. We used the analysis documents, along with the publicly available project documentation, to elicit the range of SSI connectedness based on our framework. Through these rounds of crystallization (Saldaña, 2021) and interactive discourse analysis, we arrived at our set of findings.

Defining and Operationalizing SSI Concepts

For our coding and analysis, it was important to draw on existing conceptualizations of SSI. Viehmann et al. (2024) offer some insights in their scoping review of a decade of publications, including over 100 articles on SSI in science lessons. How we understand the conduct/expectations of CitSci project participants is based on publicly available information for each project, and from this we provide our subjective but collective analysis of the projects through a constructed SSI lens. SSI as a decision-making practice have been used to support teacher planning processes for

[13] We examined only 20 projects because our overview of those in relation to our previous analysis of the total database of projects indicated that for the purposes of this article examining 20 was sufficient and that a larger sample would not result in a substantially different discussion.

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backward planning (Dauer et al., 2025). Notably, Högström et al. (2024) state that "there is no single definition advocated for [SSI] in literature" (p. 3110); thus, we drew on several rich research sources, including several systematic reviews (i.e., Smit et al., 2025; Zeidler & Kahn, 2014; Zeidler & Nichols, 2009; Högström et al., 2024), as well as our own experiences and expertise as science teachers and teacher educators. Through the literature and our own professional experience, we disaggregated SSI into the following six categories to examine 20 Canadian CitSci projects randomly selected from our database:

- social and cultural implications;
- critical thinking;
- political/governance dimensions;
- evidence-based reasoning;
- ethical and moral dimensions; and
- affective/emotional-based engagement.

Together, we argue that these categories reflect the main components of SSI learning.

In coding, team members scored the first five categories using a 6-point Likert scale, which removes a neutral option, thereby requiring respondents to take a position and providing more nuanced data (Chomeya, 2010). As described above, each project's publicly available information (through its website) was examined and scored on the first five subscales. The projects were scored from 1 to 6, with 1 being the lowest resonance or implication of each category and 6 being the highest (according to the operationalized descriptors for each project described below)

1. Social & Cultural Implications: By definition, SSI have social implications (Hodson, 2009). If the project data collection can lead to social or cultural implications, then it would score high on this scale. If, for instance, a project was about understanding how a development in a city could affect fish in a stream, then it would score higher on this scale. However, if it were a project where the participants searched photographs taken by NASA to find potential meteors, it would score lower (unless, for instance, the project described meteors as having a cultural dimension).
2. Critical Thinking: Solving problems or making decisions in the project (Where do I sample? How do I decide what bird that is?). For instance, sampling a species by counting it in your backyard is low on critical thinking, while being directed toward evaluating several places and then choosing between them is higher. Using 'your knowledge' to identify a bird based on its calls and plumage is *middle* critical thinking but doing that and cross-referencing with books and making decisions is higher. However, taking a picture and sending the picture to an AI or search engine to identify the bird species is low on critical thinking. Building and maintaining a rink about which you then collect data is higher critical thinking because there is considerable problem solving to reach the point where you can collect data.
3. Political/Governance Dimensions: This is a determination of the degree to which the CitSci activity engagement is part of or overtly mentions contributing to government policy or decision making, or engagement of the public with politicians to accomplish that, at any level (Herman et al., 2020). For example, if data collected will be used to develop policies or recommendations that will directly be shared with formal municipal government, such as counting and locating near-misses of pedestrian hits by vehicles in order to place signage, speed bumps, etc., it would rank more highly. If it is a butterfly monitoring project

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with no evidence that information is provided to government bodies, it would score lower on this scale. This relates to the idea that SSI tend to deal with controversial topics.

4. Evidence-Based Reasoning (EBR): Making decisions in the conduct of the project/data collection based on empirical evidence of some sort. It involves identifying a problem or phenomenon, gathering and examining relevant evidence, formulating an explanation, and then using the evidence to connect the explanation to evidence logically. We define EBR as having five key components: problem framing, evidence gathering, claim formulation, reasoning, and critical evaluation (Ziebell & Skeat, 2020). If a CitSci participant draws conclusions based on the evidence they collect, the project would score high; if participants engage in only one component (such as collecting evidence/data), the project would score lower. If the project participation involved collecting information based on criteria and instructions they were given and then submitting that information to a website/app, that would result in a low score. Some projects provide online access to data to allow anyone in the world to participate in interpretation, which would result in a high EBR score.
5. Ethical and Moral Dimensions: This category includes projects whose outcomes relate to an 'up' or 'down' side or have some value alignment, which may differ across social identities. Projects involving conflicting values and beliefs and making objectivity challenging, would score high in this category. If, for instance, the decision about when or where to sample provided information that may benefit one group to the detriment of another, the project would score high on this dimension. An example of a moral or ethical conflict would be found if a participant sampled and counted river biota in a stream downstream from a pulp mill that operated Monday to Friday; thus, deciding to sample on Sunday might give very different results than sampling on a Friday. However, a participant being asked to decide when to sample in this context would score highly on this category. Or if a participant could choose the river for sampling and decide whether to sample a river with a pulp mill or a river that ran out of a conservation area, that would also score high. In both cases, there is a "high" ethical/moral dimension to the actions a participant is asked to take in the project. However, if the project had participants count butterflies in their backyard, it would score lower on this scale.
6. Affective/Emotional-Based Engagements: These attend to complex issues and can involve conflicting feelings, and sometimes conflict between cognitive and emotional understandings (Herman et al., 2020). Some projects may elicit emotional reactions that may entice or deter participation. Some issues may have negative undertones, such as collecting data on roadkill, while other projects may be positively framed, indicating overt expectations of excitement or discovery. We score this across two sub-categories: What participants are doing (i.e., the 'activities' they engage in) and what the project is broadly accomplishing or its 'intentions.'

The sixth category, Affective/Emotional-Based Engagements, differs from the other categories because projects were scored based on inferences about what a participant would 'feel' about the project, which could range from negative to positive emotions. The affective/emotional category was also divided into two components: how participants might feel when engaging in the activity and how they would feel about what the overall project accomplished. Scoring on these scales was conducted differently from the other scales, using a 7-point scale with a middle "Neutral" category and the terminal ends ranging from -3 (negative emotion) to +3 (positive emotion). Each of the six categories is described in more detail below. These descriptions were provided to the team members who were evaluating the CitSci projects.

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Analysis of Coded Data

For analysis, (a) scores for each category (one from each of four researchers) were summed to provide a total score out of 18 for each project in each category, (b) these total scores were then averaged and categorized into high/medium/low with frequencies assigned to each, and (c) a total SSI score, summed across the first five categories, was calculated for each project, so that the range of CitSci projects as they related to SSI could be discussed. These were then represented graphically.

Examining Project Logos

A final part of our dataset involved an analysis of some of the graphical "logos" of a representative selection of the projects to discuss the variety of graphic illustrations used. These are part of the 'visual environment' (potential) participants encounter with the projects and contribute to their thoughts/feelings about the project. The authors analyzed these using a variation of an Interaction Analysis (Jordan & Henderson, 1995) approach, applying a semiotic lens.

Analysis/Findings

Regionality

We analyzed the projects for regional representation as part of the sociocultural and political/governance constructs, and related to place-based considerations, since locality offers variations in authentic connections to issues. Our examination of project regionality indicated that five of the 20 CitSci projects were at the municipal/local level, two were provincial, eight were national in scope, four were classified as "Other Regional" (i.e., large regions that cross provincial boundaries but do not cover entire provinces), and one was "Other" (an international project run by a Canadian institution with regional breakdowns of the data, most of which are American. It has no all-Canada representation, but it includes three provinces and several smaller Canadian jurisdictions). Some national projects were part of larger international initiatives but were identified as examining "Canadian" issues and oriented toward Canadian participants in their project descriptions.

Logo Analysis

Our analysis of project Logos reveals a variety of approaches. Figure 2 showcases logos of six of the 20 projects we randomly selected that are currently active or operated by Canadian organizations and/or researchers. Some of these are national projects, such as Birds Canada[14] or the Community Collaborative Rain, Hail & Snow (CoCoRaHS) network[15], and some are hyper-location-specific, such as that of the Tiger Mosquito project[16] in Windsor-Essex, Ontario. There are semiotic distinctions in the logos such as orientation towards kids versus adults through abstracted use of professional iconographic representations of organisms studied, and different aspects of sophistication and invitation to participate, which have implications for how a potential participant may interpret a given project.

[14] Birds Canada: https://www.birdscanada.org/.
[15] Community Collaborative Rain, Hail & Snow (CoCoRaHS) network: https://www.cocorahs.org/.
[16] Tiger Mosquito Project: https://letstalkscience.ca/outreach/uwindsor/local-programs/timo-cs.

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Figure 2

A Selection of Six CitSci Project Logos from across Canada



Interaction Analysis Discussion Summary

As discussed in the Methods section, the researchers had three one-hour discussions about their viewing of CitSci project webpages, including the publicly available materials for potential citizen scientists and the tools used to enter data. We used an Interaction Analysis approach to focus on collective observations about these materials. For the purposes of this article, we have focused on observations related to SSI-oriented concepts in our sample of 20 CitSci projects and have summarized those as follows:

- The projects covered a range of geographic focuses from local/municipal to international, which has implications for any discussions of potential participants and place-based connections to the projects.
- Project recruitment is often passive (i.e., based on interested parties finding the website through various means) as opposed to actively recruiting citizen scientists. This has implications for those who participated in such projects.
- Participation by the citizen scientists is not often directly connected to the broader goals of the science research project they are affiliated with. For instance, connections to long-range management of an organism, related government policy, and the positioning of the organism in the broader ecosystem are infrequently discussed.
- There was little (or no) opportunity for citizen scientists to participate in data analysis, summarization, or discussion of implications either directly or indirectly. Further, opportunities to discuss and critique issues with data collection methodology, a core practice of citizen scientists, were not present.

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- Few projects were structured in a manner that would encourage or facilitate the participation by students, teachers, or schools. In many cases, this did not mean the projects could not be framed in such a way that participation was more likely.
- There were few explicit connections between the CitSci projects and Indigenous perspectives on the research areas being explored (we note an exception in our broader discussion below). We noted many places where such connections could be made.

Examination of SSI Concepts

For our analysis of the project contents and their relationship to SSI, we used the six SSI-attributed categories described in the methodology, subdivided into two sets based on the scales used to code them. Thus, the Affective-Emotional category was analyzed separately from the others. We discuss our findings from this breakdown below.

Affective-Emotional Category

Two affective-emotional scales were scored from Strongly Negative to Strongly Positive emotions for participant engagement ("Activity") as well as project accomplishments ("Intentions") for each CitSci project. All scoring was based on the information provided at the publicly available CitSci website for each project, and scores were summed across the four researchers to obtain totals (frequency categories were calculated as 'Neutral' [-2 to +2], 'Medium' [(+/-)3 to 6], and 'Very' [(+/-)7 to 9]). In collating and examining these scores, we determined that two projects would elicit a high positive emotional response, 28 of the 40 affective-emotional responses displayed a lower positive emotional response, and one for each of a low and a high negative emotional response (Figure 3). This means almost half of the ratings (28/40; 10 in the "Activity" category) reflected medium-to-neutral emotional engagement potential for CitSci participants. The two projects with low Affective-Emotional scores in the "Activity" category involved data collecting/reporting about wildlife carcasses near roadsides and people documenting living with chronic pain. Overall, it is notable that 8 of 20 projects had a neutral to low "Activity" score. The projects receiving the strongest positive scores involved participants being out in nature, documenting wild flora and fauna, and contributing to a longstanding database.

Figure 3

Frequency of Affective-Emotional Category Responses

	"Activity" Freq.	"Intentions" Freq.	**Total SEL Freq.**
V. Positive	2		2
	10	18	28
Neutral	6	2	8
	1		1
V. Negative	1		1
Total # Projects	[20]	[20]	[40]

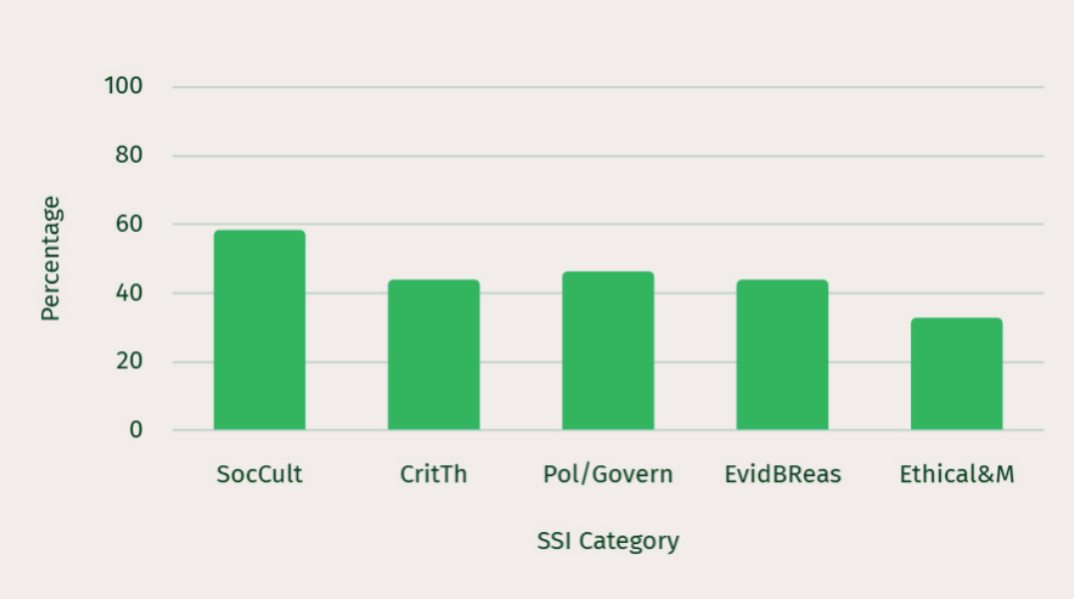
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Remaining SSI Categories

The remaining categories–Social & Cultural Implications; Critical Thinking; Political/Governance Dimensions; Evidence-Based Reasoning; and Ethical and Moral Dimensions–were scored on a Likert scale of 1 to 6 by two graduate student researchers and one researcher and author. By applying our SSI scoring tool to the publicly available webpages of 20 randomly selected projects, we observed some patterns. The median frequency for two subscales, Critical Thinking and Political/Governance, were scored in the 8 to 12 (or moderate) range, but the median frequency for Ethical and Moral Dimensions and Evidence-Based Reasoning were scored between 3 and 7, in the lower range. One category, Social & Cultural Implications, had a median score in the moderate range, but also notably had 5 scores (of the possible 20) in the higher 13 to 18 range (the other categories had 0 to 2 scores in the high range).

Figure 4

SSI Category Representation in CitSci Projects



Note. Scoring of CitSci projects was analyzed by arithmetic average response, as a percentage of 18 (the maximum possible average score in each response category).

In graphing the arithmetic average score for each of the first five SSI categories (Figure 4), it becomes evident that none of the individual scales were consistently highly scored, with social and cultural implications scored highest most often (Figure 3). Overall, these findings suggest that the potential for CitSci participation to raise understanding of SSI is poorly realized, or at least under-developed in the website texts provided to the public, despite most of the projects having, in our view, reasonably high implications for environmental knowledge gathering, understanding, and policy-influencing potential in the long term.

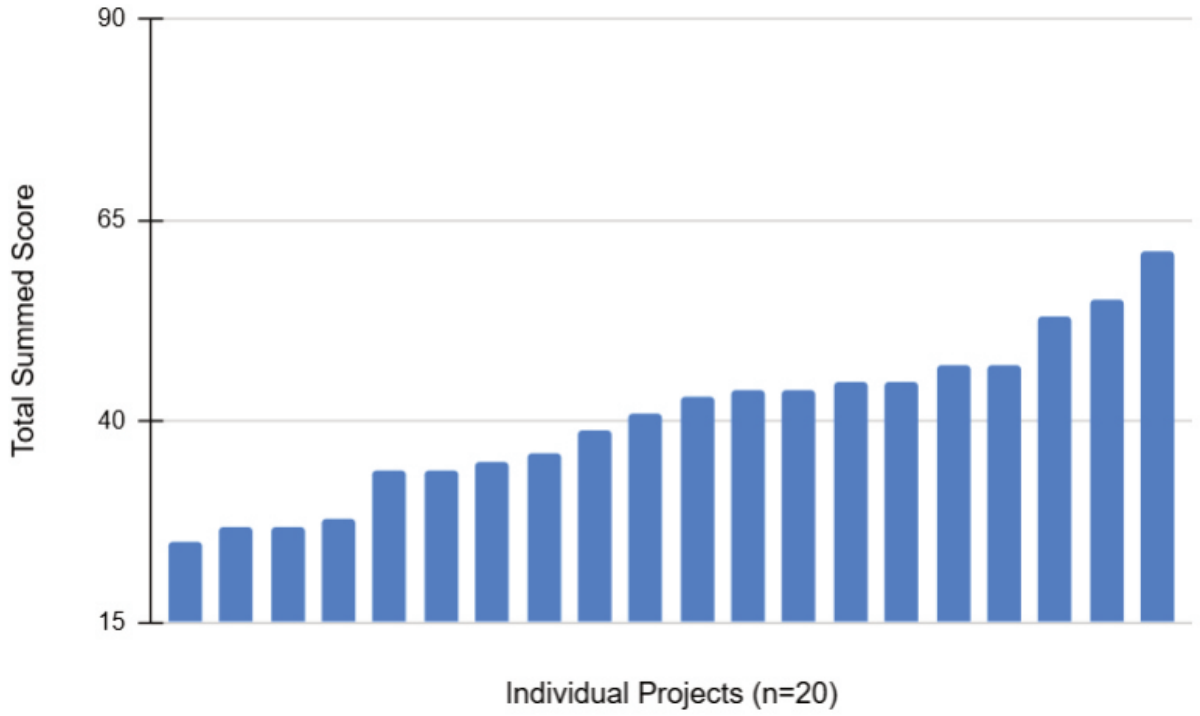
A further examination of this data set involved summing the scores across all 5 scales for each of the 20 projects to get a "Total" SSI score for each project (which were then ranked from lowest to highest). This analysis further revealed that none of the individual projects had a particularly high collective score, with a maximum score of 61 points out of a potential 90. The

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median project SSI total score was 42 points (see Figure 5, below). This further highlights that the CitSci projects we examined could better represent their connections to SSI.

Figure 5

Total SSI Scores for Each of 20 CitSci Projects



Note. Each of 20 CitSci projects across all the categories, ordered by total score, showcasing that the highest scoring project achieves a score of 61 out of a possible 90.

Impacts and Implications

Based on our scoping review, research, and analysis, we contend that there are a vast range of CitSci projects across Canada, and each attends to, or offers connections to, socioscientific teaching and learning potential in particular ways. For authentic SSI education, CitSci projects may be more valuable when they address as many of the six categories described above as possible in the public interface (websites and other materials).

As noted by Sonnert et al. (2025), as an informal science learning opportunity, CitSci may position the student as follows:

> as an autonomous learner, typically in hands-on and active learning formats that make science relevant to the students' lives … which adds to the intrinsic value [of STEM learning]. … For the individual student, the goal is to develop STEM literacy and a STEM affinity, which can be operationalized as STEM identity. The societal goal is to create a citizenry that appreciates STEM and is able to develop and hold informed opinions about STEM issues that affect society. (p. 3)

In sum, our analyses indicate that, in general, the publicly available information for recruitment, training, and data collection for the majority of the CitSci projects is not highly or even moderately

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attentive to the potential for engagement with them as SSI on many levels. For instance, even abstract and decontextualized logos do not allow potential participants to draw any affective connections to either the CitSci project itself or the broader research project. In general, this can be seen as a missed opportunity, given the research that highlights higher motivation and interest in science when SSI connections are foregrounded (Högström et al., 2024).

We did note that the highest-scoring projects on the SSI scales had the most obvious connections to government bodies and scientists, with the highest-scoring project being part of a large network of Indigenous and settler community members, federal government scientists and technicians, and industry across the country. The project entitled the Canadian Aquatic Biomonitoring Network (CABIN)[17] assesses freshwater quality and requires a high level of training to participate. It provides nationally standardized protocols and online tools to monitor and assess the health of freshwater ecosystems. The data and analytics are readily available for use by the public, including teachers. Thus, this project was incredibly robust across SSI categories but seems to offer limited access for direct student participation, which we mention as a growth opportunity.

A major goal of this overarching project is to consider how we might translate and transfer the student-level and society-level impacts of such informal, place-based learning engagements into formal education that are accessible to science teachers. We see that CitSci projects can also engage learners in practical science knowledge production and data collection. We also highlight that CitSci has considerable potential to develop participant agency, affective connection to knowledge production, sense of science identity, and democratic empowerment, all of which are constructs toward socio-ecological justice education practices (Martusewicz et al., 2020).

Reflections, Challenges, and Next Steps

CitSci projects are often run by volunteers or "off the sides of desks" (i.e., as an adjunct to their main research project and using funding provided for other projects) for many professionals. Participant recruitment may be haphazard or serendipitous, and many projects do not seem to foreground attention to participants' educational outcomes. We also note that publicly provided information on CitSci project websites does not necessarily draw direct connections to, or marketing for, what and why participation is helpful toward project and broader socioecological goals, as we would hope from the perspective of an SSI orientation.

We observed that the majority of reviewed projects were not explicit or overt about how the participant-collected data was used. In addition, there were no noted opportunities for participants to participate in the analysis or interpretation of CitSci project results, which, in most cases, were not provided to participants in any fashion, in contrast to our case study of one such project reported by Sperling and Bowen (2025). There appeared to be few mechanisms for participants to comment on the results or interpretations of the data made by those running the CitSci projects. This decontextualizes the project's value from an SSI perspective, diminishing sociocultural, ethical, and political impacts, and critical-thinking experiences (Herman et al., 2020). This deficit may impact on the potential for engagement by lacking the affective or emotional dimensions that help participants understand what the project may be achieving. In essence, in many projects, volunteers fill the role of data collectors or technicians, which means

[17] Canadian Aquatic Biomonitoring Network (CABIN) project. https://www.canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network.html.

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projects lack the opportunity for participants to comment on potential methodological problems in data collection, and participants are not viewed as expert members. This lack of input on methods can have considerable potential consequences when local expertise is ignored, as noted in a project where input from fishers was collected in a fashion that suppressed important insights from their traditional ecological knowledge (Finlayson, 1994). From an SSI perspective, this lack of opportunity for involvement in data compilation, analysis, and interpretation means that the opportunity for engaging in evidence-based reasoning, one of our scored SSI characteristics, is reasonably limited, as is the opportunity for discussion with other participants and those running the CitSci project. However, such discussion opportunities and associated collective engagements are hallmarks of SSI-oriented teaching approaches (Högström et al., 2024).

The presence of CitSci projects continues to expand in Canada and internationally. Even in the process of completing this manuscript, more projects came to light due to professional network expansions and recognition that not all CitSci projects have a robust online presence. This does not preclude such projects from working with citizens to collect 'good data' in communities. We build on the work of Falk and Dierking (2003) with our interest in engaging CitSci as an entry to science education beyond non-formal and informal learning into the formalized space, but with participation *in, with*, and *by* non-formal science actors.

Among those identified as non-formal science actors, with some controversy, we acknowledge Indigenous practices and ways of knowing the Land. We also acknowledge that Indigenous communities have been doing science, including aspects of CitSci, since time immemorial, and that while documentation processes may be more diverse and divergent from traditional Western science knowledge mobilization, Land-based practice and knowing are valuable parts of knowing the world (Johnson et al., 2016). Two-Eyed Seeing (Bartlett et al., 2012) has opened a gate of practice to work with/in these at times disparate approaches. Two-Eyed Seeing as a lens has been used in science, medicine, and science education, but not expressly or extensively in CitSci. There is some research on the intertwined value of Indigenous Ways of Knowing (IWK) with Western science practices in the South African context (Pasgaard et al., 2023), whereas there has not been a lot of research examining how IWK are woven into CitSci practice in the Canadian landscape. We believe that such a weaving can deepen reconciliation practice as well, through learning and documenting place and relationships with Land. To this point, we further noted that the descriptive text for most projects in this analysis did not encourage or promote Indigenous perspectives or participation, which is a shortcoming given that almost all projects were on environmental issues. We see potential for collaboration in the future.

We had planned to understand the place-based nature of these projects, but our examination of the regionality of projects suggests wide variation across projects. Smaller projects, such as those that are municipally based, occur in participants' communities. However, even larger projects might encourage participants to sample, count, or identify species in their backyard or neighbourhood, although participants may choose to travel to other provinces to do such collecting, or do so while on vacation. Other projects which were larger than municipal scale were intended to draw participants from locations such as cities to volunteer in more remote areas, highlighting the exotic nature of their locales. It became clear that a wide range of place-based opportunities existed and that developing a nuanced understanding of the place-based nature of Canadian CitSci projects lay beyond the scope of this current study.

Based on this research, we posit that the currently existing typology of CitSci projects would benefit from enhancement based on the SSI category integration. We intend to build on the

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existing typology of CitSci projects (NASEM, 2018) along with our addition of Makers (i.e., those who are creatively "making" tools or even the research settings to facilitate data collection to support the CitSci project), overlaying and interplaying the six categories inscribed to overlap for SSI and CitSci to potentially locate the best opportunities for implementation. Furthermore, we will apply this emerging analytical framework to all known CitSci projects in Canada.

We also note that publicly available CitSci project information could be considerably enriched to better emphasize how projects reflect many socioscientific perspectives, and that doing so might increase participation. For instance, overt articulations that data collected about the presence of a particular species mean a participant is contributing to understanding changes over time are often absent from most project descriptions. This leaves participants unaware that their project contributions are helping to understand changes in species prevalence over time, which might, in turn, lead to (better) policy decisions by governments. We also note that the Activity involvement for 40% of the projects was not positive, which is unlikely to encourage participation. Given this, and our other commentary above, we encourage CitSci projects to be structured in a manner that better involves participants in data analysis and interpretation, which could address those non-positive participation scores. As our project progresses, we anticipate writing an informational document for those who run CitSci projects so that they can consider such objectives.

Currently, we are surveying CitSci project leadership to elicit details about project goals, expectations for participants, and other information about how they intend to structure their project for public participation. The next phase of our research is to work with classroom teachers and CitSci project leaders to help identify and enhance projects for formal teaching engagements in communities. We have already begun connecting with both stakeholder groups to collaborate on good practices to achieve these goals. In this way, we aim to support and acknowledge the idiosyncratic nature of both classrooms and community-based projects toward re-bridging a new space for science education in local communities. Also, we are selecting case projects in which we will conduct research with participants to understand their experience as citizen scientists and to better understand what they have learned about the topics of the science research projects and about the conduct of science itself through their participation. We realize there is much more work to be done and great potential for learning based on the growing number and impact of CitSci projects in Canada and beyond.

Conclusions

We acknowledge that, by definition and default, CitSci has largely existed outside formal science classrooms. As our research progresses and deepens, we continue to highlight and strengthen the potential of CitSci projects as tools of practice. There is great potential to leverage the strength of an SSI framework in science and STEM education through the actions of CitSci projects. CitSci can also engage students in authentic action to deepen science literacy and scientist identity and to combat misinformation. Additionally, and perhaps of greater socioecological import, we expect that feelings of helplessness and hopelessness within this wicked time of climate change may be ameliorated through a better understanding of the processes and practices of science, which we see as emerging from a better melding of SSI perspectives and CitSci project practices and accessibility to teachers, classrooms, and the public.

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Generative AI Disclosure Statement

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References

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-eyed seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies and Sciences, 2*(4), 331–340. https://doi.org/10.1007/s13412-012-0086-8

Campos, R., & Brito, B. (2024). The role of citizen science in public engagement with socioscientific debates. *ARPHA Proceedings, 6*, 19–23. https://doi.org/10.3897/ap.e126291

Chomeya, R. (2010). Quality of psychology test between Likert scale 5 and 6 points. *Journal of Social Sciences, 6*(3), 399–403. https://doi.org/10.3844/jssp.2010.399.403

Cooper, C. B., Hawn, C. L., Larson, L. R., Parrish, J. K., Bowser, G., Cavalier, D., Dunn, R. R., Haklay, M., Gupta, K. K., Jelks, N. O., Johnson, V. A., Katti, M., Leggett, Z., Wilson, O. R., & Wilson, S. (2021). Inclusion in citizen science: The conundrum of rebranding. *Science*, *372*(6549), 1386–1388. https://doi.org/10.1126/science.abi6487

Cornell Lab of Ornithology. (2019, October 15). *About the Cornell Lab of Ornithology*. https://www.allaboutbirds.org/news/about-the-cornell-lab-of-ornithology/

Cunningham, L.E., & Tan, Y.S.M. (2026). Powerful re-/connections: The need for curriculum integration in socioscientific issues education. *Canadian Journal of Science, Mathematics, and Technology Education, 26*, Article 66. https://doi.org/10.1007/s42330-026-00491-4

Dauer, J., Kirby, C., & Sorensen, A. (2025). Defining students' socioscientific issues classroom decision-making components and practice proficiencies. *Disciplinary and Interdisciplinary Science Education Research,* 7, Article 12. https://doi.org/10.1186/s43031-025-00132-0

Eitzel, M. V., Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., Kyba, C. C. M., Bowser, A., Cooper, C. B., Sforzi, A., Metcalfe, A. N., Harris, E. S., Thiel, M., Haklay, M., Ponciano, L., Roche, J., Ceccaroni, L., Shilling, F. M., Dörler, D., … Jiang, Q. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice, 2*(1), 1–20. https://doi.org/10.5334/cstp.96

Falk, J. H., & Dierking, L. D. (2003). *Lessons without limit: How free-choice learning is transforming education.* Altamira Press.

Feinstein, N. (2011), Salvaging science literacy. *Science Education, 95*(1), 168–185. https://doi.org/10.1002/sce.20414

Finger, L, van den Bogaert, V, Schmidt, L, Fleischer, J, Stadtler, M, Sommer, K., & Wirth, J. (2023). The science of citizen science: a systematic literature review on educational and scientific outcomes. *Frontiers in Education. 8*, Article 1226529. https://doi.org/10.3389/feduc.2023.1226529

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Finlayson, A. C. (1994). *Fishing for truth: A sociological analysis of northern cod stock assessments from 1977 to 1990.* The Institute of Social and Economic Research.

Funk, C., Hefferon, M., Kennedy, B., & Courtney, J. (2019). *Trust and mistrust in Americans' views of scientific experts.* Pew Research Center. https://www.pewresearch.org/science/wp-content/uploads/sites/16/2019/08/PS_08.02.19_trust.in_.scientists_FULLREPORT_8.5.19.pdf

Governor General of Canada. (2022, December 14). *List of people invested into the Order of Canada on December 14, 2022*. https://www.gg.ca/en/media/order-canada-appointees-december-14-2022

Governor General of Canada. (2023, December 28). *Order of Canada appointees–December 2023*. https://www.gg.ca/en/order-canada-appointees-december-2023

Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation.* Sage Publications.

Hacking, N., Lewis, J., & Evans, R. (2024). Mapping approaches to 'citizen science' and 'community science' and everything in-between: The evolution of new epistemic territory? *Minerva* 62, 549–572. https://doi.org/10.1007/s11024-024-09529-z

Hancock, T. S., Friedrichsen, P. J., Kinslow, A. T., & Sadler, T. D. (2019). Selecting socioscientific issues for teaching: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science & Education, 28*, 639–667. https://doi.org/10.1007/s11191-019-00065-x

Havstad, J. C. (2020). Forty years after laboratory life. *Philosophy, Theory, and Practice in Biology, 12*, Article 3. https://doi.org/10.3998/ptpbio.16039257.0012.003

Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education, 31*(5), 1105–1139. https://doi.org/10.1007/s11191-021-00306-y

Herman, B. C., Zeidler, D. L., & Newton, M. H. (2020). Students' emotive reasoning through place-based environmental socioscientific issues. *Research in Science Education, 50*(5), 2081–2109. https://doi.org/10.1007/s11165-018-9764-1

Hodson, D. (2009). *Teaching and learning about science: Language, theories, methods, history, traditions and values*. Brill.

Högström, P., Gericke, N., Wallin, J., & Bergman, E. (2024). Teaching socioscientific issues: A systematic review. *Science & Education, 34*, 3079–3122. https://doi.org/10.1007/s11191-024-00542-y

Johnson, N., Behe, C., Danielsen, F., Krümmel, E. M., Nickels, S., & Pulsifer, P. L. (2016). *Community-based monitoring and Indigenous knowledge in a changing Arctic: A review for the Sustaining Arctic Observing Networks.* Final report to Sustaining Arctic Observing Networks. Inuit Circumpolar Council. https://www.inuitcircumpolar.com/wp-content/uploads/2019/01/cbm_report_final.pdf

Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*(1), 39–103. https://doi.org/10.1207/s15327809jls0401_2

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Kennedy, B., & Hefferon, M. (2019). *What Americans know about science.* Pew Research Center. https://www.pewresearch.org/science/wp-content/uploads/sites/16/2019/03/PS_2019.03.28_science-knowledge_FINAL.pdf

Land-Zandstra, A., Agnello, G., & Selman Gültekin, Y. (2021). Chapter 13: Participants in citizen science. In K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.). *The science of citizen science* (pp. 243–259). Springer International Publishing.

Mann, M. E., & Hotez, P. J. (2025). *Science under siege: How to fight the five most powerful forces that threaten our world.* PublicAffairs.

Martusewicz, R., Edmundson, J., & Lupinacii, J. (2020). *Ecojustice education: Towards diverse, democratic and sustainable communities* (3rd ed.). Routledge.

National Academies of Sciences, Engineering, and Medicine. (2018). *Learning through citizen science: Enhancing opportunities by design.* The National Academies Press. https://doi.org/10.17226/25183

Neves, A. T., Boaventura, D., & Galvão, C. (2024). Contributions from citizen science to climate change education: monitoring species distribution on rocky shores involving elementary students. *International Journal of Science Education, Part B*, *15*(1), 65–78. https://doi.org/10.1080/21548455.2024.2322417

Osborne, J., & Allchin, D. (2025). Science literacy in the twenty-first century: Informed trust and the competent outsider. *International Journal of Science Education*, *47*(15–16), 2134–2155. https://doi.org/10.1080/09500693.2024.2331980

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, 107(3), 553–571. https://doi.org/10.1002/sce.21790

Osborne, J. F., Pimentel, D., Alberts, B., Allchin, D., Barzilai, S., Bergstrom, C., Coffey, J., Donovan, B., Kivinen, K., Kozyreva, A., & Wineburg, S. (2022). *Science education in an age of misinformation.* Stanford University.

Osborne, J., Zucker, A., & Pimentel, D. (2023). *Tackling scientific misinformation in science education.* Stanford University.

Pasgaard, M., Breed, C., Heines, M., Knudsen, L., Brom, P., Schmidt, A., & Engemann, K. (2023). Citizen science beyond science: A collaborative approach for transformative sustainable development. *Citizen Science: Theory and Practice*, *8*(1), Article 41. https://doi.org/10.5334/cstp.574

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

Pham, M. T., Rajićm, A., Greig, J. D., Sargeant, J. M., Papadopoulos, A., & McEwen, S. A. (2014). A scoping review of scoping reviews: Advancing the approach and enhancing the consistency. *Research Synthesis Methods*, 5, 371–385. https://doi.org/10.1002/jrsm.1123

Poole, T. (2025). Investigating school belonging using socio-ecological systems theory. *in education*, 30(2), 20–45. https://doi.org/10.37119/ojs2025.v30i2.862

Saldaña, J. (2021). *The coding manual for qualitative researchers (4th ed.).* Sage Publications.

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Sandoval, W., Osborne, J., Feinstein, N., Voitle, F., Kremer, K., Duncan, R., Krishnamoorthy, R., & Tan, E. (2025). What makes a competent outsider? In A. Rajala, A. Cortez, R. Hofmann, A. Jornet, H. Lotz-Sisitka, & L. Markauskaite (Eds.), *Proceedings of the 19th International Conference of the Learning Sciences*–ICLS 2025 (pp. 2435–2441). International Society of the Learning Sciences. https://repository.isls.org/bitstream/1/11487/1/ICLS2025_2435-2441.pdf

Schultz, C., Kumm, B. E., Legg, E., & Rose, J. (2022). Emotional pedagogies: Strategies for engaging social justice in the classroom. *SCHOLE: A Journal of Leisure Studies and Recreation Education, 37*(1–2), 82–96. https://doi.org/10.1080/1937156X.2020.1777227

Shirk, J. (2024, April 2). *Reintroducing this association: Advancing participatory sciences.* Association for Advancing Participatory Sciences. https://participatorysciences.org/2024/04/02/reintroducing-this-association-advancing-participatory-sciences/

Sinatra, G. (2026). The erosion of trust is contributing to science denial. *Current Opinion in Psychology. 67,* Article 102214. https://doi.org/10.1016/j.copsyc.2025.102214

Smit, R., Rietz, F., & Büchel, D. (2025). Using the socioscientific issue approach to foster secondary students' argumentation skills, science self-efficacy beliefs and science interest. *International Journal of Science Education*, *48*(9), 1356–1372. https://doi.org/10.1080/09500693.2025.2460050

Solé, C., Couso, D., & Hernández, M. I. (2024). Citizen science in schools: A systematic literature review. *International Journal of Science Education, Part B, 14*(3), 383–399. https://doi.org/10.1080/21548455.2023.2280009

Sonnert, G., Reid, T., Sunbury, S., & Sadler, P. (2025). How do formal and informal science learning experiences during high school shape students' career interest and STEM identity? *International Journal of STEM Education*,12, Article 55. https://doi.org/10.1186/s40594-025-00568-w

Sperling, E., & Bowen, G. M. (2025). Skating on thinning ice: Backyard citizen science for climate change awareness. *Post Digital Science and Education,* 7, 143–166. https://doi.org/10.1007/s42438-024-00535-8

Tsybulsky, D., & Tal, T. (2025). *Citizen science contributions to biology and environmental education: Realities, impacts, and opportunities.* Springer International Publishing. https://doi.org/10.1007/978-3-031-99298-8

Vallerand, R. J. (2008). On the psychology of passion: In search of what makes people's lives most worth living. *Canadian Psychology/Psychologie Canadienne, 49*(1), 1–13. https://doi.org/10.1037/0708-5591.49.1.1

Van Dijk, T. (2001). Critical discourse analysis. In D. Schiffrin, D. Tannen, & H. E. Hamilton (Eds.), *The handbook of discourse analysis* (pp. 352–371). Blackwell.

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The use of socioscientific issues in science lessons: A scoping review. *Sustainability*, *16*(14), 5827. https://doi.org/10.3390/su16145827

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., & Wagenknecht, K. (2021). Editorial: The science of citizen science evolves. In K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.), *The science of citizen science* (pp. 1–12). Springer International Publishing.

Waugh, J. K., Lindsey, J. K., Stewart, M. Z., Winter, J. C., & Parrish, J. K. (2023). Demographics of public participation in science: A meta-analytic approach. *Citizen Science: Theory and Practice, 8*(1), 1–14. https://doi.org/10.5334/cstp.610

Yemini, M., Engel, L., & Ben Simon, A. (2023). Place-based education–systematic review of literature. *Educational Review*, 77(2), 640–660. https://doi.org/10.1080/00131911.2023.2177260

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

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

Zeidler, D. L., & Newton, M. H. (2017). Using a socioscientific issues framework for climate change education: An ecojustice approach. In D. P. Shepardson, A. Roychoudhury, & A. S. Hirsch (Eds.), *Teaching and learning about climate change: A framework for educators* (pp. 56–65). Routledge.

Zeidler, D. L., & Nichols, B. (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. (2023). Exploring and expanding the frontiers of socioscientific issues. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of research on science education* (Vol. III, 1st ed., pp. 899–929). Routledge. https://doi.org/10.4324/9780367855758

Ziebell, N., & Skeat, J. (2020). Evidence-based reasoning processes in education: A model to support interventionist practice. *Australian Journal of Teacher Education*, 45(3). Article 6. https://doi.org/10.14221/ajte.2020v45n3.6

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Tsi Nikahá:wi: Onkwehón:we Perspectives on Time

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Abstract

Time, a term that is normally used to refer to the experience of the continual passage of events in a sequential way, is central to how we organize our lives. In most areas of human endeavour, from the general management of one's personal life to the rather precise activities related to scientific measurement, time is understood to be linear and studied with an emphasis upon events of the past, present, and future. Although many may take a linear conception of time with precisely apportioned intervals for granted, it may be worthwhile to consider Onkwehón:we perspectives of time as one branch of the reconciliatory journey toward a science that reflects Onkwehón:we knowledges. This essay, presented by a Kanienkeha'ka social scientist who studies Onkwehón:we education and has served as an educator in First Nations school contexts, explores Onkwehón:we perspectives on time through focus upon how the passage of events is resident in the human experience and how this compares to how time is normally understood within the scientific endeavour. This exploration will contribute to ongoing dialogue on the nature of Onkwehón:we perspectives on science and how it is explored in educational settings.

Keywords: Indigenous epistemologies, Onkwehón:we science, temporality, cyclical time, science education

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Setting the Context

It may be said that modern science is fundamentally concerned with producing models of reality through scientific investigation. Otherwise stated, science is an endeavour through which people employ systematic processes such as objective observation, experimentation, and reasoning in order to understand the natural world and its resident phenomena. The products of scientific activity have, through history and the present (and at times imperfectly), helped humanity in areas such as industry, health, and security. There is little doubt that scientific inquiry and initiative have benefited human well-being and will be an essential aspect of some of humanity's pressing concerns such as climate change and communicable diseases.

For all the benefits that may be attributed to modern science and the scientific method however, there is an observation that is occasionally levied against it: its relative inability to survey some of the fundamental aspects of humanity such as human values, moral concerns, and other important aspects of consciousness. Although numerous advancements in neuroscience have helped develop an understanding of how the human brain works such as studies of electro-chemical activity amongst neurons in the human nervous system, the manner through which humans do such things as sense a self, establish a moral compass, and judge the aesthetic qualities of an environment is, ostensibly, areas for which modern science has difficulty making useful contributions (Chalmers, 1995). One of the reasons why, it is imagined, science is incapable of studying issues such as these is due to one of its central features – that of scientific reduction (Mittelstrass, 2015). Although there are numerous ways of regarding scientific reduction, a general way of describing this is the deliberate reduction of complex phenomena into its constituent elements in order to facilitate the study of the phenomenon in question (Perlovsky, 2019). This argument is sometimes adduced like this: by breaking down complex phenomena into constituent elements and representing these elements separately and/or numerically, the fundamental character of the phenomena in question is obscured or, at worst, rendered impossible to adequately study and understand (Gershenson, 2013).

The issue of scientific reduction was explored in Thomas Nagel's (2012) essay "What is it Like to be a Bat?" In this essay, Nagel focused upon the mind-body problem and how consciousness is difficult and perhaps impossible for modern scientists to study, asserting that the methods that are taken for granted in the scientific community have "led to the acceptance of implausible accounts of the mental largely because they would permit familiar kinds of reduction" (p. 166). Nagel's view on the ability of science to study and successfully describe consciousness was rather doubtful:

> We have at present no conception of what an explanation of the physical nature of a mental phenomenon would be. … The most important and characteristic feature of conscious mental phenomena is very poorly understood. Most reductionist theories do not even try to explain it. And careful examination will show that no currently available concept of reduction is applicable to it. Perhaps a new theoretical form can be devised for the purpose, but such a solution, if it exists, lies in the distant intellectual future. (p. 166)

One of the key observations made by Nagel in exploring the difficulty in scientifically investigating consciousness is the ubiquity of consciousness across species as well as the centrality that consciousness occupies in the human condition. Nagel's exploration of how consciousness is resident in the human condition leads to his fundamental claim: "an organism

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has conscious mental states if and only if there is something that it is like to be that organism – something it is like for the organism" (p. 166).

The profundity of Nagel's claim, that a conscious creature is conscious if there is something that it is like to be that creature, requires one to engage with some deliberate consideration of what it means to be conscious. Meacham (2013) and Cavanna et al. (2011) state that consciousness can be understood as the state of being awake, aware, or both. Meacham and Cavanna et al. caution on the use of the term consciousness given how many use the term expansively to mean all sorts of things. Meacham (2013) offers one example: "sometimes the term 'consciousness' means not the content but the container, that which holds or includes the content" (p. 2). Although the current discussion is related to consciousness, it is here where we will make the perhaps necessary move toward a focus upon experience; the "rich field of sensation, including emotions and thoughts, some of which fall under the spotlight of attention" (Pinker, 1997, p. 134). It is within human experience where we observe what it is like to be us. It is within human experience that we observe and interact with the world. It is within human experience where we apprehend the passage of events – what we often refer to as time.

Time, the passage of events in a discernible sequence, may be understood as an experiential concept for which we often make assumptions. For instance, we tend to assume that because we experience time, others do as well. We also assume that the general sequence of time that we experience is one that others experience as well. Husserl's (1928/1964) phenomenology of time-consciousness argues that human experience is structured through retention of the past, awareness of the present, and anticipation of the future, and that this temporal structure is understood as intersubjectively shared among subjects. Thus, we recall experiencing events of the past that may condition what we experience in the present and further inform our anticipation of events of the future, is how others experience time. We collectively apprehend, however uniformly, what time is and how this apprehension can be essential to our lives and well-being. It may be understandable why time has become an important scientific consideration as well. Because time is a concept that is foundational to the way phenomena in our world are structured, studied, and theorized, it is a topic that merits continued study.

Herein, I discuss Onkwehón:we[1] perspectives on time as one avenue toward addressing how our world may be understood and argue that time is not merely an objective external quantity measured by science, but a phenomenon structured through experience, relation, and perception. By tracing discussions of consciousness, scientific reductionism, Kantian epistemology, Onkwehón:we cyclicality, and modern physics, the essay demonstrates that differing understandings of time emerge from differing assumptions about how human beings encounter reality itself.

Onkwehón:we Perspectives on Time

Nagel's critique of reductionism raises an important epistemological question: if subjective experience cannot be fully reduced to physical description, then how is experience itself structured? Kant's (1781/1998) theory of space and time as a priori forms of intuition may provide one possible answer. Rather than existing independently 'out there' in the world, time becomes a condition through which conscious beings organize experience.

[1] Herein, the term *Onkwehón:we* (from Kanien'kehá, meaning "original peoples") will be used interchangeably with the term *Indigenous* and refers only to the First Nations, Inuit, and Metis peoples of Canada and related territories.

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Ekong (2022) put forth the following observation about time (i.e., the continual passage of events in a sequential way): that time exists only in the experience of conscious human beings. Ekong defends the Kantian view that both space and time do not exist as properties of things in themselves, but only as a priori forms of human experience. Time, on Ekong's account, is not an independently existing phenomenon outside of human experience but instead that it is a part of the structure of our conscious experience. As Ekong writes: "Kant identifies the a priori forms of sensibility: space and time, which the mind contributes, to make experience possible….an event cannot be experienced at all, unless it is recognized as being in 'space' and occurring in 'time'" (p. 34). For Ekong, time is not something that exists independently in the world, but a pure form[2] through which the human mind structures all appearances. Time, in the Kantian sense, is a necessary organizing structure that is put forth by human consciousness. Ekong's commentary may compliment what was previously stated regarding the observations of Nagel: it is like something to be human. More associated with the current discussion, it is like something to experience the continual passage of events in a sequential way. Human beings experience the passage of events. Time, in most conceptualizations that may be offered on the term, emerges from nowhere else but the experiences of conscious creatures such as human beings.

If time is understood not as an independently existing entity but as a structure of lived experience, then differing cultural experiences and relationships may generate differing temporal frameworks. Onkwehón:we perspectives on time can therefore be understood not as deviations from a universal temporal order, but as coherent experiential and relational orientations grounded in land, ancestry, ecology, and interdependence. Human beings do not necessarily experience the passage of events in the same way. It is sometimes cited that Onkwehón:we peoples experience the passage of events in ways that are different from those of other people (Cajete, 2000). There appear to be some features that are shared amongst many Onkwehón:we peoples' perspectives on time. Principal amongst these features, which may have close relation to each other in the unique manifestations of Onkwehón:we perspectives, are those of cyclicality and ecology.

Just as the seasons follow a cyclical pattern, Onkwehón:we peoples conceptualize time having a cyclic or circular form rather than the Western's linear understanding (Christie & Halpern, 1990; Hatfield et al., 2018; Janca & Bullen, 2003; MacKenzie et al., 2017; Michie et al., 2021). Such conceptualizations of time are in harmony with Onkwehón:we perceptions of the interrelatedness of all things as evidenced, for example, through the Medicine Wheel (Michie et al., 2021). As such, notions of past, present, and future may be understood to coexist in concentric time circles (Janca & Bullen, 2003). The individual abides with future and past relatives (Hatfield et al., 2018) and events may be placed closer or further from the individual in such concentric circles depending on the relevance of such events to that person (Janca & Bullen, 2003). As Hatfield et al. (2018) explain, "cyclical time or cyclical temporality, here, refers to various ways of experiencing ourselves in the world as participants within narratives involving our ancestors and descendants" (p. 3).

An integrationist approach toward the two general approaches toward understanding time may merit consideration. Christie and Halpern (1990) offer an integrationist possibility. They first explored the concept of "technical time," which is "mathematically based, mechanically, electronically or geophysically regulated, [it] is the clock and calendar time of Western society"

[2] In the Kantian sense, a *pure form* is a built-in a priori structure that is not derived from experience but rather makes experience possible.

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(p. 741). However, as the authors explain, technical time has both cyclical and linear dimensions: seasons, months, days, and minutes, they all repeat throughout time. However, even within cyclical time there is a certain quantitative precision which "ensures that its units are, by some objective measure, the same" (p. 742), thus allowing us to 'save,' 'spend,' or 'waste' time. Time can be then conceptualized as having two axes: a horizontal cyclical dimension and a vertical linear dimension (Christie & Halpern, 1990). For these authors, the Onkwehón:we worldview allows for these two axes to co-exist and, despite controversies, one is not necessarily better than the other but are rather intertwined (Krech, 2006). A problem seems to arise, however, when Western societies put too much emphasis on linear time to the detriment of cyclical time, with bad consequences for, for example, nature and human health (Christie & Halpern, 1990; Hatfield et al., 2018). In regard to possible consequences for nature, industrial systems driven by continuous economic growth and year-round extraction often ignore seasonal ecological cycles, contributing to soil depletion, overfishing, and climate instability. For human health, rigid clock-based work schedules and constant productivity expectations can disrupt natural bodily rhythms, contributing to stress, sleep disorders, anxiety, and burnout. Therefore, the Two-Ways approach (with and without epistemic insight; critical reflection on the assumptions, methods, and limits through which different knowledge traditions construct understanding) is recommended as a way to bring together Onkwehón:we and Western science education (Michie et al., 2021).

Christie and Halpern's (1990) focus was upon the rapid sociocultural change in the Canadian Arctic; specifically, the shift from traditional Inuit temporal systems to Euro-Canadian technical time. Their analysis reveals that this shift has contributed to rising mental-health challenges among Inuit communities. Traditionally, Inuit life was structured by cyclical, land-based temporal patterns tied to seasons, hunting activities, and social rhythms. However, settlement life replaced these with rigid clock-based schedules and externally imposed approaches toward life. As Christie and Halpern note, "the establishment of settlements built around Euro-Canadian institutions has created temporal environments which … regulate life on the land by eliminating the seasonality of Inuit migratory and exploitive patterns" (p. 739). For Christie and Halpern, this temporal disruption has weakened community integration, distanced younger generations from land-based identity, and created a sense of dislocation especially for settlement-born Inuit who are "temporally marginalized" and constitute the "highest risk population for mental ill-health" (p. 739). The resulting mismatch between traditional Inuit temporal orientation and the imposed technical time of the settlements contributes to rising rates of social and psychological distress, including substance abuse and suicide.

Krech (2006) was charitable to this reconciliatory effort of the sort offered by Christie and Halpern (1990) with specific focus on how time may be generally perceived within both traditions. Krech critiques the orientations of some disciplines including Onkwehón:we education that is critical of linear, chronological time and favours culturally specific, cyclical, or non-Western temporalisms. Krech (2006) argues that while Onkwehón:we conceptions of time are essential for understanding cultural meaning and worldview, being dismissive of the utility of linear time undermines the ability to analyze such things as historical change and social processes. In his view, scholars should adopt a balanced approach that incorporates both Onkwehón:we temporal frameworks and linear chronology, which is a necessary methodological tool for reconstructing historical events. Krech concludes that scholars should not view Onkwehón:we perspectives of time and those of Western scientific traditions as mutually exclusive. Instead, effective ethnohistorical research must integrate culturally specific understandings of time with chronological analysis to produce richer, more accurate histories.

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Cajete (1994, 2000) presents Onkwehón:we understandings of time as deeply relational, ecological, and cyclical rather than linear. In his 1994 work *Look to the Mountain*, Cajete focuses on the learning of Onkwehón:we perspectives and contends that time emerges through participation in the rhythms of land, ceremony, ancestry, and community. In this vein, learning is not separated into abstract units of progression but is instead embedded within seasonal and intergenerational relationships. Cajete (1994) explains that "Indigenous education is rooted in a philosophy of perpetual relationship to the natural world" (p. 209). Time, according to Cajete, is experienced through continuity with nature and with the knowledge carried by ancestors. In his 2000 work *Native Science*, Cajete expands this idea into a broader philosophical and cosmological framework. He argues that Onkwehón:we knowledge systems understand reality itself as interdependent and cyclical. He writes that "Native science is a metaphor for a wide range of tribal processes of perceiving, thinking, acting, and 'coming to know' that have evolved through human experience with the natural world" (Cajete, 2000, p. 2). Within this framework, time is not simply chronological progression, but a living process of renewal, reciprocity, and connection among past, present, and future.

Whyte (2018) extends these ideas on Onkwehón:we time and how it is experienced into contemporary discussions of colonialism and climate change. Whyte asserts that many Onkwehón:we peoples already experience environmental crises not as a distant future but as an ongoing reality rooted in histories of dispossession and disruption. This perspective challenges Western assumptions that time unfolds through linear narratives of progress. Instead, Whyte emphasizes intergenerational responsibility and ancestral continuity, noting that "many Indigenous peoples already inhabit what our ancestors would have understood as a dystopian future" (p. 227). For Whyte, Onkwehón:we time links memory, responsibility, and futurity into a single relational continuum. Both Cajete (1994, 2000) and Whyte (2018) describe Onkwehón:we temporality as grounded in land, ecological cycles, and enduring relationships among ancestors, present communities, and future generations rather than in the segmented and linear structures common to Western modernity.

Studying Onkwehón:we perspectives on science (including time) can help reveal how dominant Western perspectives and institutional practices can obscure Onkwehón:we ways of understanding the world. Although there is very little in the academic literature that offers this focus with specific consideration for time, Wilson et al. (2020) explored this topic and, in doing so, essentialized the importance for Onkwehón:we well-being. They argued that a core source of misunderstanding between Onkwehón:we peoples and settler institutions, especially healthcare, are their fundamentally different experiences of time. Non-Onkwehón:we orientations treat time as linear, progressive, and individualized; a person's medical history begins at birth, unfolds through life stages, and problems are understood as the result of personal choices across that timeline. Onkwehón:we perspectives on time, by contrast, is frequently non-linear, relational, and expansive. These perspectives on time reach back across generations, remain embodied in the present, and extend forward beyond an individual's lifespan. Past events that feature such experiences as racism in healthcare, child removal, and colonial dispossession remain active and present in shaping how Onkwehón:we people interpret contemporary experiences. As Wilson et al. (2020) assert: "For Indigenous people, the past and the future are always present and embodied within our understandings and interactions with the dominant culture and institutions" (p. 144). These differing views on time form part of what the authors call the double perspective, in which Onkwehón:we people must navigate both their own temporality and that imposed by non-Onkwehón:we institutions. When healthcare systems fail to recognize Onkwehón:we

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perspectives on time, they misinterpret behaviours, attribute blame to individuals rather than history, and overlook the ongoing effects of colonialism. According to Wilson et al. (2020), acknowledging Onkwehón:we conceptions of time by non-Onkwehón:we institutions can lead to a better understanding of Onkwehón:we experiences and designing more equitable, culturally grounded approaches to health.

In the little focus that exists in the academic literature on Onkwehón:we perspectives on time, the topic of health and well-being is a recurrent theme across works. Both Wilson et al. (2020) and Christie and Halpern (1990) focus on these areas, reporting how Inuit peoples in northern Canada have experienced psycho- and sociopathologies as a result of the disconnection between their cyclical orientation of time and the more linear orientation resident in northern settlements in or near which they reside.

Reconciling Cyclical Time and Western Science

In reconciling Onkwehón:we perspectives of time with Western scientific approaches, the aim is not to collapse Onkwehón:we temporality into modern physics nor to suggest direct equivalence between them. Rather, developments in contemporary physics complicate earlier assumptions that time is singular, universal, and absolute. In doing so, they open conceptual space for considering temporal plurality and relationality in ways that resonate with certain Onkwehón:we perspectives.

Time is a foundational concept in physics because it structures how change, motion, and causality unfold in the universe. As Newton (1687/1729) argued in his famous work *Philosophiae Naturalis Principia Mathematica*, time provides an absolute framework within which physical processes occur, allowing the laws of motion to be expressed mathematically and consistently. However, later developments, notably Einstein's (1905/1923) theory of relativity, reconceptualized time as intertwined with space, forming a four-dimensional spacetime whose geometry is shaped by mass and energy. This development in the study of physics revealed that time is not universal but instead varies for observers moving at different velocities or experiencing different gravitational fields, profoundly altering our understanding of simultaneity, measurement, and the structure of physical laws. Together, these contributions illustrate that time is not merely a backdrop for events but an active, dynamic ingredient in the physical description of reality. These contributions have been central to the developments in mainstream Western science that have essentialized the linear conception of time.

In exploring how one might understand Onkwehón:we conceptions of time herein, the notion that such conceptions merit consideration by scientists raises an important question: can one reconcile Onkwehón:we and Western scientific conceptions of time? It seems that within the current era in which Onkwehón:we knowledge is increasingly sought out and respected, this question is worthwhile addressing because (put generally) such reconciliation has the potential to allow Canadian society to (for instance) integrate long-term historical progression with the recurrent rhythms that shape ecological, cultural, and social life for everyone. Such reconciliation can foster more sustainable decision-making by highlighting how seemingly linear actions produce recurring consequences over time, something central to the seven-generations view held by many Onkwehón:we peoples. As Adam (1994) noted, recognizing multiple temporalities broadens our capacity to understand social processes and their long-range effects.

Scholarly explorations of time in various orientations (although not necessarily those of Onkwehón:we people) do predate current discussions that have involved Onkwehón:we

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knowledge and scholarship. Although never representing the prevailing view within scientific dialogue, a small number of scholars have explored time that is a departure from the mainstream Western scientific view. Caillois (1963), who had no interest in, and possibly no knowledge of, Onkwehón:we perspectives of time, contrasted two fundamental cultural conceptions of time, one of which bears some thematic overlap with Onkwehón:we perspectives: the Western model of linear, chronological progression and the Eastern model of cyclical recurrence. For Caillois (1963), Western history depends on "a rectilinear" succession of occurrences in which "each event is unique, fixed, eternal in its place" (p. 11). This model emphasizes chronology, causality, and the irreversibility of events. By contrast, many Eastern traditions view time as circular; "a chain of identical cycles … endlessly reenacted" (p. 2). In such systems, events gain meaning not from progress but from their position within recurring cosmic patterns. Caillois illustrates this through examples ranging from the Chinese 60-year cycle to the Indian kalpas spanning billions of years, all of which treat history as patterned recurrence rather than linear advancement.

Caillois (1963) shows how these differing temporal models shape historical imagination, responsibility, and cosmology. In cyclical traditions, what matters most is Kairos, which for the author refers specifically to "the moment in which each event occurs…This instant largely determining the occurrence" (p. 8). Meanwhile, Western thought generally insists on accumulated human agency, rejecting doctrines like eternal recurrence because they threaten the idea of moral responsibility. He notes that even when cyclical ideas reappear in the West, they never overturn the deep assumption of linear development. Caillois demonstrates that both views coexist latently. For this author, even the most linear historians subtly fall into cyclical patterns when describing civilizations passing through phases of "gestation … flowering … [and] decadence" (p. 12).

A circular conception of time has been expressed by Caillois and others as valuable because it highlights patterns, rhythms, and recurring conditions that shape human experience; thus, the relevance to Onkwehón:we knowledge and thought might be understood. Caillois (1963) notes that cyclical frameworks treat history as structured by "moments with fixed properties" that succeed one another in predictable ways (p. 9). This perspective corresponds and even supports those Onkwehón:we perspectives on time mentioned earlier in so far as they point to the importance for individuals and societies to recognize recurring opportunities and dangers, anticipate cycles of growth and decline, and respond more thoughtfully to the conjuncture, the kairos, or opportune moment, rather than assuming all change is linear or unprecedented.

The Kairos concept as offered by Caillois (1963) brings us into an issue explored at the outset of this essay – that of human experience and it how it mediates phenomena in our world. At times, the experiential aspect of understanding our world is through the observations we make of it. Although this is clearly a facet of those who retain an orientation toward the circular conception of time or even an Onkwehón:we conception of time, there are some scholars of mainstream Western science who have included the importance of human observation and experience into their own studies. Werner Heisenberg is one of some high-profile physicists who maintained that electrons do not always exist and only exist if they are being observed (Jaroszkiewicz & Eakins, 2006).

Carlo Rovelli (2014) offers one of a small number of descriptions of time that are at once a departure from what may be regarded as mainstream Western science, an affirmation of the achievements of mainstream Western science, and an acknowledgement of how human beings may apprehend the passage of events in particular ways. Although Rovelli does affirm that time

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is not a fundamental feature of the universe and does hover over the notion that thermal phenomena such as entropy gives rise to what might be understood as the passage of events, he also offers a subtle but important commentary on how time (the passage of events) is conditioned by our limited consciousness. As he states: "Physicists and philosophers have come to the conclusion that the idea of a present that is common to the whole universe is an illusion and that the universal 'flow' of time is a generalization that doesn't work" (2014, p. 60). Is there a straightforward journey to reconciling Western scientific understandings of time with those of whose understandings are orientated toward a non-linear view? Perhaps this journey requires confronting the contexts in which we find ourselves applying such understandings. Although some might posit that Western scientific discussions have no 'space' for non-linear approaches and/or vice versa, we have explored enough herein to point toward the importance of exploring their reconciliation and sampled some of the theoretical antecedents that support its importance. Perhaps the semantics related to our understandings of time matter more than we realize. It may be said that views on time that are resident in contemporary Western science may correspond to an experiential apprehension of time. The concept of circular time might overlap with other areas of scientific concern.

Discussion: Semantics and the Utility of Experience

The essay now returns to the earlier critique of reductionism. If modern physics operationalizes time through measurable periodicity, then Onkwehón:we temporal frameworks foreground dimensions of lived experience that may resist such reduction. The contrast is therefore not between 'scientific' and 'non-scientific' understandings, but between different ways of organizing and interpreting temporal experience.

Anderson (1972) explored how phenomena in our world cannot be fully understood just by knowing all there is to know of their simplest parts. Although acknowledging the role that the reductionist view has in the scientific endeavour, Anderson's work considers how natural phenomena emerge from constituent parts and are not readily analyzable with a reductionist approach. As stated earlier, this sort of approach may be useful in considering how we may understand time.

In the Western scientific tradition, particularly in physics, time is understood in terms of measurable quantities, or so-called 'standards of measurement.' The current standards for time and space measurements are both taken from the same reference; periodic oscillations of light emitted from a particular atom in a particular manner.

It is the oscillation that may be particularly interesting as this is something that repeats identically. That is why it is chosen as a base unit for measurement. Amongst physicists, this repetition is used to define time, and there is an associated distance that is travelled by the light during its oscillation which defines length. Using a definition of periodicity lies at the heart of what is meant for time and space in physics and is also used in a fundamental way for defining quantum mechanics. We define the inverse of these oscillation periods as quantities used to describe waves and, consequently, quantum states. In physics this periodic repetition is exact; one cannot say of a wave that any particular oscillation is unique. There is no identity for a wave except through its periodicity. Physicists who study quantum mechanics would assert that a particle can be in a particular state, but that state does not define any portion of a wave, only the length or time interval associated with the wave.

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As intimated earlier, one may wonder if there is a consequence from this sort of definition of time and space in terms of periodicity that appears as a limitation on what physics is able to describe. There seems to be difficulty for physics to describe events that are one-off in any terms other than the probability of their occurrence. One may observe this trouble as a direct consequence of using periodicity as a basis for defining measurable states in quantum mechanics; these observables must always be described as possibilities that are delineated by the consequences of periodicity (Busch et al., 2016).

An observation made by some (Buonomano & Rovelli, 2023; Frischhut, 2016) might be that in contrasting this Western scientific approach, such as our awareness of days and years, it seems that very little is periodic in our everyday experience. Such things as colour, which is the basis for physicists' measure of time and space, is perceived by us in a way that is quite personal and subjective. For some, what is seen as red even depends upon which eye a person uses through which to observe that colour. In terms of events and their passage, it may seem that each event is unique, even if it is similar to other events. Could it be that one's personal experience can never be described by physics in ways that are based on periodicity?

At a level of personal and experiential analysis, time is not simply a phenomenon of investigative interest that may be studied within a paradigm of scientific reduction in which perfection of measurement is sought. It may be said that time, the continual passage of events, is a part of one's experiential reality and a factor in the process of organizing one's life. Unique features of the passage of time might be understood with a focus upon how periodicity is resident in that passage of time, but to do so at the expense of the experiential would be to miss an important aspect of the Onkwehón:we paradigm and how the passage of events is understood by Onkwehón:we peoples. As cited above, many scholars have reflected on the ways many Onkwehón:we peoples apprehend time in a way through which stories and experiences are central. Where scientists employ principles of periodicity to study/describe how to measure the continual passage of events, many Onkwehón:we peoples will speak of seasons, events, and generations and how passing/future events are a part of their lived experience.

This discussion is offered in the English language. The language employed to explore how one may apprehend the passage of events matters. It has been said that language conditions meaning and informs the constitution of worldview in rather important ways (Fontaine, 2025). When Battiste and Henderson (2000) referred to the cultural landscape of Onkwehón:we peoples, they described it as the "unique manifestations of Indigenous knowledge, heritage, and consciousness" (p. 35). The exploration of these manifestations may be best initiated through the meaning and cultural references that are resident in the languages of those peoples (Deer, 2025). If one wished to know what word or phrase a Kanienkeha'ka (Mohawk) person would use for the English word "time," one might use the term tsi nikahá:wi which may be understood to mean "It is now time" or "when it is time." There is no term that articulates the passage of time as a noun in this language in the way it appears in English. Although this is an observation of a particular concept as it is reflected in a particular Onkwehón:we language, this observation is generalizable to other Onkwehón:we language contexts. For some Onkwehón:we groups, temporalities are not reflected in simple terms that denote the passage of events only; in some cases, they reflect experience in the form of such things as kinship, continuity, and prophecy (Awasis, 2020).

Understanding time, whether in Western scientific terms or in those of Onkwehón:we peoples who observe non-linear orientations, may be difficult for us as conscious creatures not just because the theoretical aspects are complicated or that the experiential aspects do not lend to

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shared need for such things as temporal measurement. Instead, this discussion may cause us to confront that the difficulty is us and our limitations. Hoffman (2019) explored these limitations in ways that leads to a potentially uncomfortable notion: not only is it the case that human beings cannot accurately perceive and even understand ourselves, our universe, and phenomena of various sorts (including time), but if we did, it would be maladaptive for us.

To explore this, Hoffman (2019) employed the fitness-beats-truth theorem that posits that natural selection does not favour organisms that perceive reality as it truly is, but rather those that perceive reality in ways that enhance survival and reproductive success. In this view, accurate perception is often unnecessary and energetically costly. Instead, simplified, distorted, or strategically biased perceptions can offer faster and more adaptive responses to the environment. The theorem emphasizes the notion that the human mind has evolved perceptual and cognitive systems tuned not for truth, but for usefulness, filtering and reshaping the world into a set of symbols that guide effective behaviour rather than reveal objective reality. This means that even our most confident intuitions about the world may be deeply misleading, making the pursuit of truth far more difficult than our everyday experience suggests. It is within this neuroscientific framework that experience has an important part to play. However, it plays this part imperfectly because human experience is exactly that: imperfect.

Perhaps the fundamental problem regarding how human experience affects our understanding of time is best reflected by Rovelli (2017) who offered an interesting notion: we are not in time; we are time. It exists, as Ekong (2022) put it, within human experience. If it is important for us to consider Nagel's main point that consciousness requires one to consider if it is like to be something, then it is here where we ought to put forth a natural extension: it is like something to be Onkwehón:we. The perspectives that emerge from the unique manifestations of Onkwehón:we knowledge, heritage, and consciousness affect the views, conceptualizations, and analyses of our world, ourselves, and our relations. It also affects how we, Onkwehón:we, understand time.

This essay is intended to explore Onkwehón:we perspectives on time that may contribute meaningfully to ongoing discussions about how Onkwehón:we science may be understood. By foregrounding relational, cyclical, and experiential understandings of our world that differ from dominant Western scientific conceptions of linearity, it is hoped that educators will seriously consider such Onkwehón:we frames for inquiry. Drawing on Onkwehón:we and non-Onkwehón:we scholarship, this essay explored Onkwehón:we perspectives on time not merely as a quantifiable sequence of events, but as something embedded within experience including relationships with territory, ancestors, community, ecology, and future generations.

This essay suggests that Onkwehón:we science may be understood as a knowledge tradition grounded in lived experience, interdependence, and continuity rather than exclusively through reductionist frameworks. By examining how Onkwehón:we temporalities intersect with questions of experience, ecology, language, wellness, and cosmology, the discussion broadens the conceptual terrain through which science itself may be interpreted in educational contexts. Onkwehón:we science education is a developing field of study and practice. Conversations about Onkwehón:we science education may be enhanced by illustrating that differing understandings of scientific topics such as time are not simply cultural variations, but foundational epistemological perspectives that may deepen scholarly and educational dialogue concerning the nature, scope, and meaning of science within public schools.

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References

Adam, B. (1994). *Time and social theory*. Polity Books.

Anderson, P. W. (1972). More is different. *Science, 177*(4047), 393–396. https://doi.org/10.1126/science.177.4047.393

Awasis, S. (2020). "Anishinaabe time": Temporalities and impact assessment in pipeline reviews. *Journal of Political Ecology, 27*(1), 830–852. https://doi.org/10.2458/v27i1.23236

Battiste, M., & Henderson, J. S. (2000). *Protecting Indigenous knowledge and heritage: A global challenge*. Purich Publishing.

Buonomano, D. & Rovelli, C. (2023). Bridging the neuroscience and physics of time. In R. Lestienne (Ed.), *Time and science* (pp. 267–282). World Scientific Publishing.

Busch, P., Lahti, P., Pellonpää, J.-P., & Ylinen, K. (2016). *Quantum Measurement*. Springer.

Caillois, R. (1963). Circular time, rectilinear time. *Diogenes, 11*(42), 1–13. https://doi.org/10.1177/039219216301104201

Cajete, G. (1994). *Look to the mountain: An ecology of Indigenous education*. Kivaki Press.

Cajete, G. (2000). *Native science: Natural laws of interdependence*. Clear Light Publishers.

Cavanna, A. E., Shah, S., Eddy, C. M., Williams, A., & Rickards, H. (2011). Consciousness: A neurological perspective. *Behavioural Neurology, 24*, 107–116. https://doi.org/10.3233/BEN-2011-0322

Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies, 2*(3), 200–219.

Christie, L., & Halpern, J. M. (1990). Temporal constructs and Inuit mental health. *Social Science & Medicine, 30*(6), 739–749. https://doi.org/10.1016/0277-9536(88)90260-2

Deer, F. (2025). Investigating public school language initiatives in Northern Manitoba. *Brock Education Journal, 34*(2), 73–89. https://doi.org/10.26522/brocked.v34i2.1217

Einstein, A. (1923). On the electrodynamics of moving bodies. In H. A. Lorentz, A. Einstein, H. Minkowski, & H. Weyl (Eds.), *The principle of relativity* (W. Perrett & G. B. Jeffery, Trans., pp. 35–65). Methuen. (Original work published 1905)

Ekong, J. T. (2022). Space and time as a priori forms of human intuition in Kant's epistemology. *International Journal of Scientific and Management Research, 5*(5), 34–43. https://doi.org/10.37502/IJSMR.2022.5504

Fontaine, L. S. (2025). *Living language rights: Constitutional pathways to Indigenous language education*. University of Manitoba Press.

Frischhut, A. M. (2016). Commentary: The phenomenology and perception of time. In F. Santoianni (Ed.), *The concept of time in early twentieth-century philosophy: A philosophical thematic atlas* (pp. 109–117). Springer.

Gershenson, C. (2013). The implications of interactions for science and philosophy. *Foundations of Science, 18*(4), 781–790. https://doi.org/10.48550/arXiv.1105.2827

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Hatfield, S., Marino, E., Whyte, K. P., Dello, K. D., & Mote, P. W. (2018). Indian time: Time, seasonality, and culture in Traditional Ecological Knowledge of climate change. *Ecological Processes, 7*(1), 1–11. https://doi.org/10.1186/s13717-018-0136-6

Hoffman, D. (2019). *The case against reality: Why evolution hid the truth from our eyes*. W.W. Norton.

Husserl, E. (1964). *The phenomenology of internal time-consciousness* (J. S. Churchill, Trans.). Indiana University Press. (Original work published 1928)

Janca, A., & Bullen, C. (2003). Indigenous time. *Australasian Psychiatry, 11*(Suppl. 1), S40–S44. https://doi.org/10.1046/j.1038-5282.2003.02009.x

Jaroszkiewicz, G., & Eakins, J. (2006). Bohr-Heisenberg reality and system-free quantum mechanics. *AIP Conference Proceedings, 889*, 85–94. https://doi.org/10.1063/1.2713452

Kant, I. (1998). *Critique of pure reason* (P. Guyer & A. W. Wood, Eds). Cambridge University Press. (Original work published 1781)

Krech, S. (2006). Bringing linear time back in. *Ethnohistory, 53*(3), 567–593. https://doi.org/10.1215/00141801-2006-005

MacKenzie, K., Siabato, W., Reitsma, F., & Claramunt, C. (2017). Spatio-temporal visualisation and data exploration of Traditional Ecological Knowledge/Indigenous Knowledge. *Conservation and Society, 15*(1), 41–58. https://doi.org/10.4103/0972-4923.201391

Meacham, W. (2013). *Consciousness and experience*. https://www.bmeacham.com/whatswhat/PDF/ConsciousnessAndExperience_v1_8.pdf

Michie, M., Rioux, J., & Hogue, M. (2021). Incorporating two-ways thinking about time into the science curriculum. *Teaching Science, 67*(1), 36–43. https://doi.org/10.3316/informit.674942136512231

Mittelstrass, J. (2015). Complexity, reductionism, and holism in science and philosophy of science. In W. Arber, J. Mittelstrass, & M. Sánchez Sorondo (Eds.), *Complexity and analogy in science: Theoretical, methodological and epistemological aspects* (pp. 45–53). Libreria Editrice Vaticana. https://www.pas.va/content/dam/casinapioiv/pas/pdf-volumi/acta/acta-22-pdf-papers/acta22-mittelstrass.pdf

Nagel, T. (2012). *Mortal questions*. Cambridge University Press.

Newton, I. (1729). *The mathematical principles of natural philosophy* (A. Motte, Trans.). Benjamin Motte. (Original work published 1687)

Perlovsky, L. (2019). Reductionism: Simplified and scientific. *Behavioral and Brain Sciences, 42*, Article e21. https://doi.org/10.1017/S0140525X18001127

Pinker, S. (1997). *How the mind works*. W. W. Norton & Company.

Rovelli, C. (2014). *Seven brief lessons on physics*. Riverhead Books.

Rovelli, C. (2017). *The order of time*. Riverhead Books.

Whyte, K. P. (2018). Indigenous science (fiction) and the Anthropocene: Ancestral dystopias and fantasies of climate change crises. *Environment and Planning E: Nature and Space, 1*(1–2), 224–242. https://doi.org/10.1177/2514848618777621

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Wilson, S., Svalastog, A. L., Gaski, H., Senior, K., & Chenhall, R. (2020). Double perspective narrating time, life and health. *AlterNative: An International Journal of Indigenous Peoples, 16*(2), 137–145. https://doi.org/10.1177/1177180120920774

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(Re)framing Socioscientific Issues in Canadian Science Education: A Relational, Indigenous, and Posthumanism Approach

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Abstract

This paper explores how socioscientific issues (SSI) can be enacted within science education through relational, posthumanism, and Indigenous epistemologies. We argue that conventional Western science (WS) education often presents knowledge as abstract, objective, and disconnected from social, cultural, and ecological contexts which reinforces human exceptionalism and superiority. Drawing on SSI, posthumanism, and Indigenous knowledges-sciences (IK-S), we foreground relationality, reciprocity, and ethical responsibility and position learners as engaged participants in complex webs of networks rather than isolated beings. We highlight relationality to illustrate how these perspectives inform pedagogical possibilities. Through a Two-Eyed Seeing approach, we outline examples that integrate SSI, posthumanism, and IK-S with relational, land-based, and ethical responsibility. Finally, we argue that teacher education must provide dedicated spaces for pre- and in-service training to support the enactment of innovative, embodied, and relational SSI pedagogy. Ultimately, we advocate for a transformative model of science education that cultivates learners' empathy, humility, and ethical engagement in our common world.

Keywords: socioscientific issues (SSI), relationality, posthumanism, Indigenous knowledges-sciences (IK-S), science education

IN EDUCATION

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(Re)framing Socioscientific Issues in Canadian Science Education: A Relational, Indigenous, and Posthumanism Approach

Within conventional Western education, science is often presented as a collection of disconnected facts, abstracted from the students' everyday relationships that give knowledge meaning (Aikenhead, 1996; Snively & Corsiglia, 2001; Tsing & Bazzul, 2022). In presenting scientific knowledge as universal and objective, it often reinforces a reductionist view of the world which decontextualizes knowledge and neglects the more-than-human relations that contribute to our meaning-making (Boileau, 2024; Jukes et al., 2021). Additionally, environmental education narratives within schooling (and elsewhere) position children as future saviours; that is, as agents responsible for saving our planet (Taylor, 2013, 2017), eventually leading to a utopian future. This framing then extends into how education is conceptualized and how dualisms are further reinforced when children (and adults) are positioned as superior to nature rather than learning with and becoming with the more-than-humans (Pacini-Ketchabaw et al., 2016).

The inclusion of socioscientific issues (SSI) in the classroom presents a view of science education as one that is deeply entangled with civic, cultural, social, political, and ecological contexts rather than as objective, isolated knowledge (Viehmann et al., 2024). This paper situates SSI alongside both Indigenous Knowledges-Sciences (IK-S), which emphasize reciprocity and relationality between humans and more-than-humans (Aikenhead & Michell, 2011; Kimmerer, 2002), and posthumanism approaches that reject anthropocentric hierarchies and focus on relational becoming (Braidotti, 2013; Ferrando, 2019, 2024).

What follows is intended as a theoretical position paper that draws on relational and interdisciplinary scholarship to imagine new possibilities for science and environmental education. We present a conceptual synthesis of SSI, posthumanism, and IK-S education through a Two-Eyed Seeing (TES) framework and explore the challenges and possibilities of its practical inclusion within education policy and the classroom. We begin by foregrounding our positionalities and the relational histories that shape us. Though the three of us grew up in different parts of the world, our experiences with and within the realm of the more-than-humans have had profound, yet unique and distinct influences on shaping and enacting who we are and who we are becoming. Our shared commitment to education and educational research is inextricably linked to these experiences. From these stated vantage points, we then discuss how posthumanism and IK-S offer relational onto-epistemological foundations for the teaching of SSI within science and environmental education. Following this, we juxtapose posthumanism, IK-S, and SSI education to illustrate how they may be synthesized to elaborate new perspectives and approaches for ethical science education. Employing a TES approach, examples are outlined to help illustrate what these types of synergies may look like in the classroom. Finally, we discuss the operationalization of SSI within science education, including teacher training, as a relational onto-epistemology.

Ultimately, we argue that by foregrounding relationality, science education can move beyond a content-driven model toward a situated, land-based practice of becoming-with that helps learners navigate SSI with complexity, empathy, humility, and ethical responsibility. Such a (re)imagining represents a transformative shift in how science education understands knowledge, relationships, and our shared futures in the Common World that we co-inhabit (Taylor, 2013).

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Our Stories of Relational Becoming With/in Land

Floriane

Growing up in Western France, I have fond memories of playing freely in the garden, biking and wandering in the nearby countryside. We would collect the apples; my father would cultivate a huge vegetable garden and my mother would harvest. We would eat our homegrown food throughout the fall and winter and begin the cycle again the next growing season. I had the privilege of vacationing in the Alps every year, skiing for two weeks in the winter and camping for a month in the summer. These early experiences of exploring and playing outdoors have profoundly shaped my understanding of learning and my commitments as an educator. As a teacher in Eastern Canada for the last fifteen years, I have taught every level from kindergarten to teacher education courses, and I feel very passionate about the need for the educational system to change so it can offer meaningful, embodied, outdoor relational learning experiences to all students. I believe every child should have equal opportunity to develop into ecologically literate citizens.

Steffie

I was born and raised in a post-colonial region on the west coast of India, within a Vadval community where most families relied on farming for their livelihood. Generations of my ancestors cultivated the land, and my own childhood unfolded through relationality with place and more-than-humans. While my formal schooling centered on structured forms of knowledge, discipline, and rote memorization, the learning that occurred beyond the classroom continues to hold deeper meaning. We spent afternoons plucking flowers alongside my parents and grandparents. We weighed and counted the flowers and packed them into banana leaves or small bags to be sold in local markets. These embodied practices nurtured our mathematical thinking, ecological awareness, and understandings of seasonality, plant cycles, labour, and interdependence. Knowledge and learning were lived, sensed, and co-created through entangled relations with land and community. Reciprocity was/is an integral part of our community. I now write as an immigrant scholar residing on the unceded and unsurrendered Algonquin Anishinaabe territory. My social, cultural, and educational experiences influence my commitment to relational pedagogies that honour diverse ways of knowing and call for meaningful attentiveness to the more-than-humans within shared ecological futures.

Michelle

Growing up in the Canadian Northern Ontario town of Sudbury, I spent much of my childhood playing, learning, and exploring outdoors. Some of my favourite summers were spent on Mnidoo Mnising, known in English as Manitoulin Island. I spent countless hours swimming and fishing in the cool waters of Lake Huron and hiking the Cup and Saucer trail with my cousins. As a child, I knew this land was home to many Anishinaabe communities, but our worlds rarely intersected. It is only as an adult that I have begun to understand the deep relational, spiritual, and reciprocal relationships held by the First Nations of Mnidoo Mnising. As my understanding has grown, so too has my connection with the land. While I cannot claim the depth of relationship that emerges when identity is co-constituted with a sentient land, it has reshaped my sense of responsibility, care, and accountability. As a non-Indigenous settler ally, engaging with Indigenous knowledges (IK) demands more than theoretical understanding; it calls for a continual praxis of epistemic humility and relational accountability. This includes not only

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unlearning colonial habits of thought but also confronting the structures that sustain them and working to unsettle and transform colonial dynamics within education and educational research.

Posthumanism and Relational Onto-Epistemologies

In this section, we draw on posthumanism and Indigenous relational perspectives to (re)imagine science education and SSI. We explore how these perspectives can unsettle human-centered assumptions and foster more relational and ethical engagements with the more-than-human world.

Posthumanism as Relational Approach to Knowing and Learning

Posthumanism offers a lens to re-examine, unsettle and (re)configure our assumptions of children as learners who must be taught rather than beings who are already engaged with the world through embodied, sensory, and relational ways of knowing (Murris, 2022; Nxumalo & Pacini-Ketchabaw, 2017). As such, we ask: How might posthumanism guide our pedagogical approaches within science education, particularly when engaging with SSI? What shifts are needed for science education in Canada (and elsewhere) to respond meaningfully to posthuman thinking and SSI?

Posthumanism challenges human exceptionalism by decentering the human and foregrounding relationality within complex networks of beings, forces, and histories (Riley et al., 2024). The post in posthumanism does not imply a world 'after humans' or the disappearance of the human. Instead, it signals a shift away from the humanist ideal of the autonomous, rational, bounded individual (Ferrando, 2019; Nayar, 2014). As scholars (e.g., Braidotti, 2013; Haraway, 1985, 2016) argue, we are already posthuman; we are continually constituted through dense, dynamic networks of relations with technologies, microbes, materials, environments, and more-than-humans who co-shape who we are and how we come to know the world. Barad's (2006) work provides a powerful provocation here; they argue that entities do not pre-exist their relations but rather come into being through their ongoing intra-actions (i.e., beings are not separate, isolated entities that then relate; instead, they emerge through their entanglements with one another) (Barad, 2006). This challenges the assumptions that center humans as the principal meaning-makers of the world and instead situate humans as one among many co-constitutive participants in vast relational ecologies. Our understanding of the world is never neutral because it is embodied through our actions, which in turn shape the world around us. Consequently, what is called for is an ethics of teaching and learning grounded in accountability and care. Hence, posthumanism opens up perspectives for affirmative (re)configurations of both subjectivity and the very conditions through which theory and knowledge are produced, by moving toward more relational, ethical, and multispecies modes of existence (Braidotti, 2013).

Through our readings on Indigenous epistemologies (Donald, 2021; Kimmerer, 2024; Kovach, 2021; McGregor, 2013) and through reflection on our own lived experiences as individuals from diverse communities, we have come to understand that the ideas associated with posthumanism are not new in any literal sense (Nail, 2023). Indigenous peoples within Canada (and elsewhere), as well as people from diverse communities, (e.g., Steffie's Vadval community in India) have long maintained relationality with more-than-humans (Patterson et al., 2023). Hence, posthumanism is not a novelty but rather signals a critique of longstanding traditions that privilege human-centered rationality and agency over material, ecological, and relational forces (Nayar, 2014).

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Indigenous Knowledges-Sciences (IK-S) as Relational Ways of Knowing

Before moving on to a discussion of IK-S, it is important to emphasize that IK are place-based and specific to their local context. They cannot be reduced to a monolithic body of knowledge. Whenever possible, classroom engagements with IK-S should be grounded in the knowledge, languages, histories, and teachings of the local Indigenous Nations on whose lands students are learning. At the same time, there are enough similarities between Indigenous philosophies generally, and North American Indigenous worldviews more specifically, that general concepts may be discussed while still holding space for individual differences and emphases (Little Bear, 2000).

Articulated by an animate language, Indigenous epistemologies describe a world "as one of flux, motion, and interrelationship" (Kovach, 2021, p. 70). In this worldview, knowledge is more than a body of information. It is a way of life grounded in relationships with others, the land, and the more-than-human beings that inhabit it (Mazzocchi, 2008). It is also rooted in a spiritual dimension expressed through connection to a larger external force (Kovach, 2021) and in ongoing entanglements with the world we inhabit. Such inter-connections preclude the clear divisions of ontology, epistemology, and axiology, that reflect a Western preference for categorization.

Building on this rejection of fixed categories, defining Indigenous sciences (IS) as a distinct subset of IK reflects a Western convention that packages Indigenous practices and knowledges to "fit within existing academia's cultures and values" (Kim et al., 2017, p. 260). In fact, it is impossible to differentiate between them because they are interconnected in ways that shape and respond to one another, reflecting a holistic understanding of the world that rejects the isolation of phenomena from their wider contexts. As such, Kim (2018) uses the term Indigenous knowledges-sciences (IK-S) to capture the interdependent relationship between IK and IS. IK-S is a living process that integrates empirical, ethical, cultural, and spiritual knowledges whereby "nothing is simply a cause or an effect, but all factors are influences impacting other elements of the systems as-a-whole" (Freeman, 1992, p. 10). It is from this understanding that we adopt this terminology to reflect the relational and interconnected character of IK and IS.

IK-S is a robust body of empirical knowledge embedded within an interconnected set of relationships (Kimmerer, 2013), which have been developed over thousands of years of living in sustained kinship with a sentient land and the myriad lives that inhabit it. Knowledge, therefore, is not an individual pursuit but a collective one enacted through relationships among people, communities, and the more-than-human world (Cajete, 2000; Kimmerer, 2013). Tewa author and educator Gregory Cajete explains that "reality is wholly interrelated – knowledge emanating from an Indigenous worldview has to be understood relationally. Nothing exists in isolation or can be understood apart from all its relationships" (as cited in Goodchild, 2022, p. 55). Western Science (WS) often considers environmental and social factors to be "confounding" (Snively & Corsiglia, 2001, p. 11). As such, WS is often conducted in isolated laboratories or under strict control in the field, but this is not the world we inhabit. The interconnectedness of our lives with each other, with the material and with the more-than-human is not apart from our reality, together they constitute our reality. In contrast, IK-S represents integrated ways of knowing, being, and doing that are inseparable from the land, community, and lived experience. Together, WS and IK-S provide us with both micro- and macro-level perspectives and help us to understand how these parts function as a whole.

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Ultimately, scientific knowledge alone is insufficient for addressing the complex ecological and social challenges we face; it must be tempered by wisdom and guided by an ethics of reciprocity (Davis & McMurtry, 2025; Snively & Corsiglia, 2001). It is in this space that posthumanism, IK-S, and SSI come together to nurture learners who think critically, act responsibly, and engage with the world through relations of care and accountability.

Toward Relational and Situated Science Education Through the Entanglement of SSI, Posthumanism, and IK-S

The overarching goal of SSI is to foster the development of students' scientific literacy, thereby enabling them to become active and engaged citizens equipped with the decision-making skills needed to consider the relational interplay between scientific and social issues (Högström et al., 2025). Although SSI represents an important move toward situating science within broader societal contexts, it remains largely grounded in WS and Western socio-economic perspectives. In their recent scoping review, Viehmann et al. (2024) found that the vast majority of SSI publications (in English or Spanish) originated from the United States, Spain, and Germany, with comparatively few contributions from non-Western countries. All this to say that the underlying assumption is that the literacy, knowledge, and communication skills being cultivated through SSI approaches reflect Western scientific and societal goals.

We also recognize that posthumanism theories are similarly rooted in Western intellectual traditions. Even as posthumanism scholarship appears in universities and journals outside of Europe and North America, the conversations remain shaped by Western thought, including its critiques of the Western humanist tradition and its particular constructions of the 'human' (Rubins, 2019). In this sense, posthumanism may universalize this concept and overlook other existing conceptions of humanity. However, while acknowledging their eminence from dominant Western frameworks, we believe that SSI and posthumanism relational approaches can create opportunities for more relational, inclusive, and ethically attuned ways of teaching and learning within science education.

While these relational approaches find affinity with IK-S, the latter emerges from an Indigenous episteme and therefore brings a fundamentally different orientation to science education, whereby learning is facilitated through participation and reflection (Aikenhead & Michell, 2011). Where SSI emphasizes preparing learners to imagine and evaluate possible solutions to complex socioscientific challenges, IK-S foregrounds the work of restoring right relationships as the basis for any such solutions. IK-S also challenges presumptions about who gets to define which relationships matter and opens space for decolonizing approaches that unsettle assumptions about whose knowledge counts and whose interests science is meant to serve (Harding, 1991).

Similarly, a posthumanist relational approach allows students to see complex SSI not only as an interplay between human science and socio-political factors, but also as a dynamic entanglement of humans, nonhumans, and material forces. Children do not merely observe their environment; they intra-act with it (Barad, 2006). That is, their actions, perceptions, and understandings are entangled with what they encounter, whether it is a plant, an insect, water, stones, or soil (Rautio, 2013). These encounters constitute phenomena in which neither the child nor more-than-humans pre-exist as independent agents; rather, they emerge through their intra-actions (Harwood & Collier, 2017). In these moments, children and the environment co-constitute one another, each shaping the possibilities, actions, and learning of the other (Cutter-

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Mackenzie-Knowles et al., 2020). Complementing SSI's critical and ethical examination of contemporary issues, posthumanism invites us to attend to the entangled relationalities of challenges such as climate change, water management, and/or biodiversity loss. This approach foregrounds how human decisions are inseparable from more-than-human agencies and local material realities (Atkinson, 2015; Nxumalo & Pacini-Ketchabaw, 2017). In doing so, students are encouraged to explore how humans, non-humans, and environments co-inhabit our shared world, rather than viewing nature as a backdrop to human activity or a resource to be managed (Taylor, 2017).

Examining these same SSI issues from an IK-S lens encourages students to explore how these concerns are rooted in relationships and how proposed responses might mend, or further strain, those connections. Translating these concepts into SSI teaching means (re)imagining classroom inquiry as relational work rather than strictly problem-solving. For teachers, this invites pedagogical moves such as grounding SSI units in local land-based contexts, incorporating Indigenous narratives and community voices, and prompting students to consider reciprocity alongside scientific evidence (McGregor, 2013). A communal understanding of knowledge frames learning, not as an individual pursuit, but as a collective process grounded in community and place. In this way, cultivating relational responsibility grounds the critical reasoning needed for informed decision-making within a broader web of relationships (Aikenhead & Michell, 2011). Such a relational view of teaching and learning reminds us that knowing is situated: it matters who speaks, from where and in relation to what. This emphasis is also central to posthuman ethics and avoids reproducing the universalizing tendencies of traditional humanism (Braidotti, 2013, 2019). For example, in India, Steffie, observed that the same farm holds very different meanings for children. For some children who visit the farm during summer vacation, it is merely a site of play, while for children from some communities (e.g., Adivasi) the same farm is part of everyday life and labour. Such differences challenge the assumption within traditional science education that all children might encounter 'nature' in similar ways and can therefore learn about it through standardized activities. What this example serves to illustrate is that these relationships are neither romantic nor universal; they are shaped by social, economic, cultural, political and complex material conditions that create very different possibilities for how children come to know and co-inhabit the land (Malone, 2020).

As we consider these orientations together, it is important to resist the temptation to collapse them into direct comparisons. The focus on constant comparison can obscure the dynamic, relational and emergent qualities that animate SSI, posthumanism, and IK-S, and reduce them to static categories rather than living practices (Barad, 2003). Instead, we treat these theoretical approaches as active, material-discursive forces that shape how learners notice, interpret, and respond within their environments (Atkinson, 2015; Barad, 2014). In this view, IK-S, posthumanism, and SSI are not frameworks to be measured against one another but are to be considered as mutually generative onto-epistemologies that expand what science education can become when grounded in relationality, responsibility, and situated engagement. Their entanglement opens space for pedagogical approaches that braid multiple ways of knowing, which we explore next through the guiding principle of TES.

To support teachers in weaving relational responsibilities with scientific inquiry, TES offers a meaningful starting point. It is a guiding principle first introduced by Mi'kma'ki Elders Albert and Murdena Marshall in 2004 (Rankin et al., 2023). Inspired by the Mi'kma'ki word,

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Etuaptmumk, which means "the gift of multiple perspective [*sic*]" (Bartlett et al., 2015, p. 295), TES calls for:

> learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of Western knowledges and ways of knowing, and to use both these eyes together, for the benefit of all. (p. 295)

Rather than merging knowledge systems, TES invites teachers and learners to 'weave' back and forth between knowledges, calling upon the strengths within IK-S or WS as required (Bartlett et al., 2015). Both offer different ways of understanding a problem and working together can offer unique and innovative solutions (Cirkony et al., 2023).

The application of TES in this approach could be considered from the perspective that one of the eyes sees through the Western-centered approaches of SSI and posthumanism, while the other eye provides a view through Indigenous epistemologies and IK-S. However, here it is important to remember that the English translation of *Etuaptmumk*, *Two-Eyed Seeing*, is not meant to convey a binary. All knowledges are partial and situated (Haraway, 1988), and as Elder Albert Marshall explains, they all have insights and understandings to contribute. In this sense, one might just as easily speak of Three-Eyed Seeing, Four-Eyed Seeing, or more. In this context, TES is not merely a matter of pairing WS and IK-S content, it offers a generative way to bring IK-S, posthumanism, and SSI into productive relationships in classroom practice. SSI pedagogies support inquiry-based engagement with complex scientific and societal issues through approaches commonly associated with WS. IK-S, in turn, foregrounds relational, ethical, and land-based responsibilities that broaden how these issues are understood and addressed. Posthumanism further invites students to see organisms, environments, technologies, and humans as co-constitutive and co-shaping one another. Cirkony et al. (2023) have shown that these kinds of pedagogical 'weavings' are possible when educators intentionally combine the inquiry-based models of pedagogy often employed with SSI (Högström et al., 2025; Viehmann, 2024) with relational, story-rich, and place-centred approaches of IK-S and Indigenous ways of learning and knowing.

Let us now consider how TES can guide teachers in bringing posthumanism, IK-S, and SSI together by briefly outlining two examples.

Example of Pimìzì (American eel) in the Kitchissippi (Ottawa River)

The story of pimìzì in the Kitchissippi, which runs through the traditional territory of the Anishinaabe Algonquin people in present-day Ontario and Québec, demonstrates how IK-S, posthumanism, and SSI can be meaningfully woven into science education. Kitchissippi pimìzì populations have drastically declined by about 99% as a result of dams and habitat fragmentation (Ottawa Riverkeeper, n.d.). As a culturally and ecologically significant species, it risks disappearing from the waters of the Kitchissippi. The Kitchissippi pimìzì is an important traditional source of food and medicine and holds deep spiritual significance for the local Anishinaabe Algonquin. Archaeological evidence dating back more than 5,000 years reveals that one of the largest pimìzì harvesting sites in North America was situated on a Kitchissippi island west of Ottawa (Algonquins of Ontario, 2014). For the Algonquins, the eel holds sacred significance and is understood as a carrier of prayers, moving through rivers, wetlands, and subterranean passages in ways that connect the waters and lands of Mother Earth (Algonquins of Ontario, 2014).

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This example serves to highlight a suite of interconnected ecological, political, policy, and conservation challenges. Employing a TES framework, educators can combine SSI activities with story-rich, land-centered learning that encourages students to explore these entanglements, reflect on ethical responsibilities, and recognize agency as not situated within any individual but rather distributed within this intra-action. Such pedagogical 'weaving' can potentially foster critical, relational, and ethical understanding and cultivate ecological literacy that is attuned to the co-constitutive dynamics of living systems within shared ecological worlds. Posthumanism and IK-S encourage us to move beyond what solutions humans can implement toward mapping the complex relationalities among infrastructure, river flows, eel biology, human policies, and broader ecological systems. This perspective emphasizes co-constitution: humans, eels, rivers, design, and technologies co-shape one another and what patterns emerge from these entanglements rather than from isolated actions (Rosén, et al., 2024).

Example of Classroom Inquiry into Local Water Quality

Another example is a classroom inquiry into local water quality, where students are invited to draw on both relational responsibilities and scientific reasoning. From a TES perspective, WS facts regarding the physical and chemical properties of water would be accompanied by an invitation for students to enter into a relationship with water as a living relative that moves, responds, sustains kin, and gives of itself. This orientation prompts students to ask not only "What is happening to this water?" but also "What responsibilities arise from this relationship, and what do we owe in return?" As McGregor (2013) highlights, "while people are caretakers of water, we do not 'manage' or 'control' it; it has its own life force that must be respected" (p. 83). In this context, TES means valuing community testimony, land-based observations, and local stories as legitimate forms of knowledge alongside pH readings and contaminant assays.

From an integrative and relational SSI perspective, this same classroom inquiry not only requires learners to analyze Western scientific data but also consider how contaminants affect human and more-than-human ecosystems, how harms are unevenly distributed across communities and what intersecting political, economic, and social justice interests must be weighed when examining possible responses. For example, many Indigenous communities on reserves continue to face long-term issues with safe drinking water. Although some progress has been made in recent years, as of May 2026, there were 39 active long-term drinking water advisories affecting 37 Indigenous communities across Canada (Government of Canada, n.d.).

As such, rather than focusing on 'fixing' the problem or finding a solution solely from a human perspective, a posthumanism perspective would extend this line of inquiry by asking: How do humans and nonhumans intra-act in this ecosystem? What patterns and assemblages emerge out of these intra-actions? Whose needs and interests are prioritized in decision-making: Are they those of fishers, politicians, fish, seabirds, or shoreline vegetation? How do water cycles, industry, climate change, and human interventions co-produce the current ecological situation? Through a posthumanism lens, SSI approaches can be expanded to work with these interconnected forms of inquiry, allowing students to form assemblages and recognize that agency is distributed across humans, nonhumans, and broader environmental forces (Boileau, 2024). Here, IK-S also intersects with the social and ethical dimensions of SSI and posthumanism by prompting students to ask which relationships have broken down or become strained—among people, water, communities, governance structures, human settlements, more-than-human worlds, and more. Such an inquiry attends to how these complex, myriad,

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interconnected, and/or fractured relationships shape both the causes and the consequences of contamination.

Working with diverse epistemologies, including IK-S, in ways that are meaningful to students' own local contexts can empower learners to see themselves, their families and their broader communities as legitimate sources of knowledge and as agents capable of addressing the issues they face (Kayumova & Dou, 2022). However, we recognize that working across these epistemological divides is not without its challenges. Reflecting on the concept of *settler moves to innocence* (Tuck & Yang, 2012), it may often feel easier and safer for non-Indigenous educators to excuse themselves from the tension, ambiguity, and discomfort of engaging with Indigenous epistemologies and knowledges because they may be afraid of making a mistake, and it is simply "not my stories to tell" (Sargent, 2021, p. 46). However, as Cree scholar Dwayne Donald (2021) explains, if we are to (re)new and (re)imagine our relationships, including Indigenous-Canadian relations as well as those with the other-than-human, then educators must "engage in such topics in qualitatively different ways" (p. 61). It is not meant to be easy or straightforward; it requires both the deconstruction of oppressive epistemic systems and the reconstruction of more relational and pluralistic ones (Battiste, 2013). As Tuck and Yang (2012) argue, "Settler colonialism and its decolonization implicates and unsettles everyone" (p. 7).

In this context, TES offers an approachable and collaborative framework through which educators may bring SSI, IK-S, and posthumanism into dialogue. Together, they can co-cultivate ethical, affective, and civic engagement by opening space for epistemic as well as disciplinary pluralism. However, as previously discussed, current practical applications of SSI frameworks frequently remain centered on Western scientific ways of knowing, which can limit how relational, land-based, and more-than-human perspectives are taken up. Hence, it is crucial to understand how we can move forward toward more meaningful forms of relational and systemic transformation. We therefore now turn to the operationalization of SSI as a relational pedagogy and discuss the barriers and opportunities relating to the enactment of these approaches within educational practice.

Enacting SSI Relationally: Toward System Transformation

There is often a disconnect between pedagogical intentions and their actual implementation in classrooms (McLaughlin & Ruby, 2024). The reasons for the difficulty in turning relationally focused pedagogy into reality are multiple and multi-layered (Field et al., 2024). This tension becomes particularly visible in the enactment of SSI with topics such as climate change, biodiversity loss, and/or water contamination. Returning to the previous example of the decline of pimìzì populations in the Kitchissippi, we can see how ecological degradation is entangled with colonial histories, hydroelectric infrastructures, conservation policies, and Indigenous relationships to land and water. Engaging with this topic therefore requires learners to attend to these complexities, adopt a holistic stance, and explore relationships between physical, biological, and social sciences. However, classroom inquiries often become reduced to technical or scientific analyses, while relational, historical, ethical, and political dimensions remain peripheral. Teachers may also face uncertainty regarding how to engage with IK, facilitate discussions around colonialism and environmental injustice, and/or work with emotionally and politically complex issues within institutional constraints (Roberts, 2024). Consequently, while SSI frameworks conceptually support relational and transdisciplinary engagement, their enactment frequently remains limited by existing educational structures, epistemic norms, and lack of teacher training in this area.

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First, we need to be upfront about the fact that IK-S and posthumanism inspired SSI teaching is countercurrent in the Canadian and global context where educational systems are themselves embedded in neoliberal logics of competition and performativity (Ball, 2021; Pinto, 2015). Reflecting logics of modernity, these systems often reinforce linear ways of knowing, fixed notions of progress and development, hierarchical relations of power, and the separation of humans from the more-than-human world (Machado de Oliveira, 2025; Stein, 2018). This ideological context affects the possibility to invest time and money away from standardized testing's main criteria of success (i.e., literacy and numeracy). For example, provincial school boards are funded based on a complex formula that relies largely on the number of students registered. Therefore, school boards need to attract students by highlighting features such as their academic scores or the high employability of their students (DiMartino & Jessen, 2018). An education system that is entangled in competitive structures (i.e., university rankings; public scores of national and international standardized testing), often runs counter to relational pedagogical values of interconnectedness, sharing, and reciprocity.

Nevertheless, some jurisdictions have tried to draft policies supporting relational pedagogies. For example, in Ontario, Environmental Education (EE) was 'infused' across all subject areas rather than taught as a distinct stand-alone program. Yet this approach has been shown to further marginalize EE. As Karrow and Fazio (2015) explain, this infusion "falls short of preserving the holistic nature of EE. It takes the holistic nature of EE, carves it up into pieces and inserts these pieces into other curricular areas" (p. 98). While the intention of this policy was to support EE, its practical implementation failed to manifest its intended goals. Nevertheless, the Ontario experience with EE integration is instructive because the EE policy framework (Ontario Ministry of Education [OMoE], 2009) aligns closely with the goals of SSI. It promotes experiential and inquiry-based approaches and encourages transdisciplinary investigations of complex natural and social phenomena, all to cultivate "future scientifically conscious and active citizens" (Viehmann et al., 2024, p. 2). While some educators and administrators have used these policy documents (OMoE, 2009, 2013) to develop innovative programs, EE has not yet fully flourished at the systemic level in Ontario (Bardecki & McCarthy, 2020). Reasons are numerous, including (but not limited to): lack of pre- and in-service teacher training, absence of an accountability mechanism on the part of school boards, lack of ministry budget, lack of time due to pressure to cover the curriculum, dominant grammar of teaching that remains traditional and not conducive to pedagogical risk-taking, deep-seated culture of neutrality, and rationality attached to science teaching (Bardecki & McCarthy, 2020; Barrett, 2007; Gough & Gough, 2020).

What we learn from the Ontario context is that well-intentioned policy making and curriculum integration are necessary, yet not sufficient. If these policies are not accompanied by adequate and meaningful supports for successful policy enactment, progressive reform efforts are at risk of stalling and not delivering on their promise. In the current neoliberal context, marked by an unprecedented volume of prescriptive policies, educational leaders' central role as the "meaning-makers" (Pinto, 2015, p. 140) who interpret and enact these policies is being challenged and constrained. Pinto (2015) argues that educational leaders feel "compelled to produce an illusion of policy compliance by way of performativity" (p. 152), which may translate into minor or cosmetic changes rather than meaningful, well-executed initiatives.

In the Canadian context with ten provinces and three territories who all have their own educational jurisdictions, these challenges are all the more problematic. Field et al. (2024)

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describe how climate change education is unevenly applied across Canadian provinces and calls for stronger leadership and collaboration across provincial educational ministries to ensure that all students, regardless of geographic location or course choices, receive meaningful education on this issue. This uneven education across the country raises important questions about how younger generations will grapple with such complex phenomena, particularly in an increasingly polarized context, where political adversaries openly distrust one another (Schedler, 2023).

Therefore, in such a current landscape it is important to acknowledge the challenges of implementing widespread SSI teaching practices, including relational theories. For posthumanism and IK-S inspired SSI pedagogy to be taken up by teachers, and for embodied, relational, transdisciplinary learning experiences to take root, significant systemic changes are required. Such changes must go beyond minor modifications to existing frameworks and/or the introduction of additional policies, particularly within a context in which school and district administrators are already operating under significant constraints. Fortunately, these challenges are not insurmountable, and there is hope to operate deep, meaningful changes within the educational system. In line with IK-S and posthumanism pedagogies as communal endeavours, Shah (2026) posits hope as something that does not belong to the individual but rather emerges through relationship, conversation, and the shared work of imagining other worlds. Many dedicated and passionate administrators and educators are striving to disrupt the status quo and put in place innovative programs, prioritizing relationality for individual and collective flourishing while illustrating the principle that "there is almost always a place for the exercise of positive choices and agency" (Walker et al., 2021, p. 316).

Analyzing how leaders function in schools that are driven by positive psychology, rather than identifying deficits and ways to solve these gaps, Walker et al. (2021) crafted a conceptual framework for flourishing based on four principles: purpose, presence, passion, and play. The authors emphasize interconnectedness as key in fostering a "sense of enjoyment, meaning, purpose, and connectedness" (p. 5) in schools, which seems very congruent with a wider relational enactment of SSI in schools. This also suggests that relational enactments of learning require organizational structures that support sustained engagement with complexity, uncertainty, and collaborative inquiry (Machado de Oliveira, 2025; Stein, 2018). For example, adjusting timetables for longer periods of time for student inquiries, creating opportunities for land-based and community-engaged learning, supporting teacher networks, and ongoing training can foster relational and affective conditions required for this non-traditional pedagogy to take place. Such practices move beyond transactional models of schooling toward educational environments that recognize learning and knowing as an emergent, relational, and co-constitutive process (Machado de Oliveira, 2025). In this sense, flourishing is not an isolated achievement but a relational process emerging through reciprocity, care, and mutual responsibility. We also draw inspiration from Kimmerer's (2024) assertion that "all flourishing is mutual" (p. 28) which emphasizes that the wellbeing of humans, communities, lands, waters, and more-than-human worlds is fundamentally interconnected. Relational leadership therefore becomes significant not only for fostering institutional flourishing, but also for cultivating the ethical and relational conditions through which collective flourishing and transformative educational possibilities may emerge.

These stories of positive leadership are based on leaders' personal traits and their capacity to rise above an ever-increasing workload to bring the organization further. While this cannot be expected of all educators in the system, it does speak to the role of inner development

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within overall system transformation. Katie Hodgetts (2026) has coined the term inner-tersectional changemaking to express that lasting change demands a union of inner development and political reform. She argues that sustainable changemaking demands more than external action; it also requires profound internal transformation. This rightly puts into focus a significant limitation of much educational leadership preparation. Under the influence of standards-based accountability and performance pressures, leadership programs have often privileged managerial, administrative, and technical competencies, while giving comparatively limited attention to the moral, relational, reflective, and personally developmental dimensions of leadership (Spooner, 2024).

Relational leadership is premised on the idea that it is the relationship between the leader and their followers that makes leadership not a determined set of skills exercised by a highly qualified leader (Clarke, 2018). "All too often we reduce relational experiences to an objectified, causal transaction between two people" (Giles, 2019, p. 5). Relational leadership should instead be considered a holistic, embodied, dynamic, and context-dependent process that recognizes the complex interplays between several factors such as the individuals themselves, both leader and followers, their own previous experiences of being in relationship, the organizational culture, and broader cultures (Clarke, 2018; Giles, 2019). In a complex and rapidly changing world, relational leadership is seen as a social influence process within which change can emerge through intentional practices of co-construction between a leader and their followers (Nicholson & Kurucz, 2019). Away from managerialist, top-down conceptions, we are convinced that the practice of relational leadership, which is intrinsically reflective and collaborative, is essential in fostering innovation in educational contexts. It invites leaders to continuously and holistically reflect on their own inner development, ethics, and way of being, as well as organizational goals, thereby nurturing positive relationships and achieving meaningful and lasting change.

While discussing whether SSI should be promoted as a subject in its own right or not, we as authors encountered tensions and complexities in arriving at a shared conclusion. Some of us believe that SSI should exist as a standalone subject, while others argue that it should remain integrated across curricula. Considering the challenges educators face when engaging with SSI within already crowded disciplinary curricula (Avraamidou, 2016; Gough & Gough, 2020), one argument is that SSI should be a stand-alone subject with its own curriculum, so that educators can be adequately trained and engage with it more meaningfully. According to this position, SSI would require the creation of a transdisciplinary space, with its own pre- and in-service training, methodologies, and pedagogical tools capable of supporting ethical, affective, epistemic, and ecological forms of inquiry. Alternatively, there was value in weaving SSI approaches and pedagogies across disciplines. The significance of SSI lies not only in where it is positioned within the curriculum, but also in how it invites educators and learners to engage ethically, relationally, and responsively (beyond their curricula) with complex socio-ecological issues.

While we all agreed that SSI and other relational pedagogies should be prominent within curricula, there was critical discussion regarding whether making it a stand-alone subject would risk siloing cross-curricular connections or whether it would provide the recognition and support needed for it to thrive. In navigating these dialogues, we considered how multiple epistemologies coexist without one agenda or policy expectation being positioned as more legitimate than another (Machado de Oliveira, 2025, p. 44). In this sense, our dialogue itself disrupts Cartesian assumptions that privilege linear and universal ways of knowing (Roberts, 2024). Instead, it foregrounds plurality, uncertainty, ambivalence, and relational negotiation (Machado de

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Oliveira, 2025) which resists the oversimplification of SSI and acknowledges the ongoing tension and complexity involved in imagining its place within education. Regardless of these differing lenses, we collectively agree that SSI risks being diluted if it is not intentionally supported. This is important because educators that seek to foster relational accountability, ethical responsiveness, and emotional and epistemic growth in their students are often faced with dominant systemic trends shaped by standardization, performativity, and disciplinary compartmentalization. Thus, pre-service and in-service teacher education must include training that enables teachers to embrace uncertainty, complexity, ambiguity, hold space for emotion and ethics and draw on diverse epistemologies in their practice (Machado de Oliveira, 2025). This is an ambitious goal and as such needs to have its own spaces/referents in faculties and school boards, to allow for (re)imagining and enacting innovative, embodied, and relational pedagogies.

Finally, we encourage the creation of new alliances and synergies to ensure the sustainability of SSI as a relational pedagogy. Teacher educators also need to work closely with local school boards' pedagogical consultants to develop a coherent pre- and in-service training program that offers lifelong learning opportunities to dedicated teachers, in partnership with Indigenous and environmental community organizations. These partnerships are already in place in a few faculties and school boards that have prioritized system transformation to support land-based learning and Indigenization of pedagogy (Karsgaard et al., 2025; Schnellert et al., 2024). However, these efforts are not yet widespread. SSI approaches are best enacted by educators who are familiar with critical scholarships and can navigate educational, scientific, and socio-political dominant discourses with discernment. Effective SSI teaching, including adequate preparation for IK-S and Etuaptmumk/TES, cannot be sustained without an adequate budget to finance the creation of training/support hubs linking school boards to faculties of education and community organizations.

Conclusion

This paper offers an entry point into how diverse ways of knowing can be meaningfully woven into science education. By bringing IK-S, posthumanism, and Western scientific practices into dialogue, educators can cultivate the epistemic and intellectual diversity needed for students to approach SSI with greater critical insight. Engaging with multiple epistemologies strengthens ecological literacy (Black & Tylianakis, 2024) while also fostering the ethical sensibilities and civic responsibility that support an engaged citizenry. Attending to the relational and more-than-human dimensions of inquiry encourages learners to consider the responsibilities that arise within the complex webs of relations that shape our shared world. Taken together, these approaches nurture a relational and ethically attuned science education that prepares students to navigate and respond thoughtfully to the challenges of the complex world we co-inhabit (Taylor & Giugni, 2012).

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References

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27*(1), 1–52. https://doi.org/10.1080/03057269608560077

Aikenhead, G. S., & Michell, H. (2011). *Bridging cultures: Scientific and Indigenous ways of knowing nature*. Pearson Canada.

Algonquins of Ontario. (2014). *Bridging the gap between scientific and Aboriginal traditional knowledge: Exploring Algonquin and Aboriginal relationships with the American eel* (Volume 2: Traditional knowledge report). http://www.tanakiwin.com/wp-system/uploads/2013/10/AOO_Traditional-Knowledge-Report_Volume-2_E-Version_Pimisi_Final_20140814.pdf

Atkinson, K. (2015). Wasps-bees-mushrooms-children: Reimagining multispecies relations in early childhood pedagogies. *Journal of Childhood Studies, 40*(2), 67–79. https://doi.org/10.18357/jcs.v40i2.15180

Avraamidou, L. (2016). Stories of self and science: Preservice elementary teachers' identity work through time and across contexts. *Pedagogies: An International Journal, 11*(1), 43–62, https://doi.org/10.1080/1554480X.2015.1047837

Ball, S. J. (2021). *The education debate*. Policy Press.

Barad, K. (2003). Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs, 28*(3), 801–831. https://doi.org/10.1086/345321

Barad, K. (2006). *Meeting the universe halfway*. Duke University Press. https://doi.org/10.1215/9780822388128

Barad, K. (2014). Diffracting diffraction: Cutting together-apart. *Parallax, 20*(3), 168–187. https://doi.org/10.1080/13534645.2014.927623

Bardecki, M., & McCarthy, L. (2020). Implementation of the Bondar Report: A reflection on the state of environmental education in Ontario. *Canadian Journal of Environmental Education, 23*, 113–131. https://cjee.lakeheadu.ca/article/view/1585

Barrett, M. J. (2007). Homework and fieldwork: Investigations into the rhetoric–reality gap in environmental education research and pedagogy. *Environmental Education Research, 13*(2), 209–223. https://doi.org/10.1080/13504620701284928

Bartlett, C., Marshall, M., Marshall, A., & Iwama, M. (2015). Integrative science and Two-Eyed Seeing: Enriching the discussion framework for healthy communities. In M. W. Parkes, N. P. Guehlstorf, & L. K. Hallström (Eds.), *Ecosystems, society, and health* (pp. 280–326). McGill-Queen's University Press. https://doi.org/10.1515/9780773583122-012

Battiste, M. (2013). *Decolonizing education: Nourishing the learning spirit*. Purich Publishing. https://doi.org/10.59962/9781895830972

Black, A., & Tylianakis, J. M. (2024). Teach Indigenous knowledge alongside science. *Science, 383*(6683), 592–594. https://doi.org/10.1126/science.adi9606

Boileau, E. (2024). Navigating approaches to "thinking with": A discussion of the practicalities of posthuman research involving young children. *Australian Journal of Environmental Education, 40*(2), 216–230. https://doi.org/10.1017/aee.2024.30

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Braidotti, R. (2013). *The posthuman*. Polity Press.

Braidotti, R. (2019). A theoretical framework for the critical posthumanities. *Theory, Culture & Society, 36*(6), 31–61. https://doi.org/10.1177/0263276418771486

Cajete, G. (2000). *Native science: Natural laws of interdependence*. Clear Light Publishers.

Cirkony, C., Kenny, J., & Zandvliet, D. (2023). A Two-Eyed Seeing teaching and learning framework for science education. *Canadian Journal of Science, Mathematics and Technology Education, 23*(2), 340–364. https://doi.org/10.1007/s42330-023-00276-z

Clarke, N. (2018). *Relational leadership: Theory, practice and development*. Routledge. https://doi.org/10.4324/9781315620435-1

Cutter-Mackenzie-Knowles, A., Malone, K., & Hacking, E. (2020). *Research handbook on childhoodnature: Assemblages of childhood and nature research*. Springer.

Davis, B., & McMurtry, A. (2025). *Inventions of teaching: A genealogy* (2nd ed.). Routledge. https://doi.org/10.4324/9781003493440

DiMartino, C., & Jessen, S. B. (2018). *Selling school: The marketing of public education*. Teachers College Press.

Donald, D. (2021). We need a new story: Walking and the wâhkôhtowin imagination. *Journal of the Canadian Association for Curriculum Studies, 18*(2), 53–63. https://doi.org/10.25071/1916-4467.40492

Ferrando, F. (2019). *Philosophical posthumanism*. Bloomsbury Academic.

Ferrando, F. (2024). *The art of being posthuman: Who are we in the 21st century?* Polity Press.

Field, E., Berger, P., Lee, D., Strutt, C., & Nguyen, A. T. (2024). Knowledge, urgency and agency: Reflections on climate change education course outcomes. *Environmental Education Research, 30*(11), 2108–2130. https://doi.org/10.1080/13504622.2023.2296359

Freeman, M. M. (1992). The nature and utility of traditional ecological knowledge. *Northern Perspectives, 20*(1), 9–12.

Giles, D. L. (2019). *Relational leadership in education: A phenomenon of inquiry and practice* (1st ed.). Routledge.

Goodchild, M. (2022). Relational systems thinking: The Dibaajimowin (story) of re-theorizing "systems thinking" and "complexity science". *Journal of Awareness-Based Systems Change, 2*(1), 53–76. https://doi.org/10.47061/jabsc.v2i1.2027

Gough, A., & Gough, N. (2020). Series editors' foreword. In D. D. Karrow & M. DiGiuseppe (Eds.), *Environmental and sustainability education in teacher education* (pp. v–ix). Springer.

Government of Canada. (n.d.). *Active long-term drinking water advisories*. https://www.sac-isc.gc.ca/eng/1614387410146/1614387435325

Haraway, D. (1985). *A cyborg manifesto*. University of Minnesota Press. https://theanarchistlibrary.org/mirror/d/dh/donna-haraway-a-cyborg-manifesto.pdf

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Haraway, D. (1988). Situated knowledges: The science question in feminism and the privilege of partial perspective. *Feminist Studies, 14*(3), 575–599. https://doi.org/10.2307/3178066

Haraway, D. J. (2016). *Staying with the trouble*. Duke University Press. https://doi.org/10.1215/9780822373780

Harding, S. G. (1991). *Whose science? Whose knowledge? Thinking from women's lives*. Cornell University Press.

Harwood, D., & Collier, D. R. (2017). The matter of the stick: Storying/(re)storying children's literacies in the forest. *Journal of Early Childhood Literacy, 17*(3), 336–352. https://doi.org/10.1177/1468798417712340

Hodgetts, K. (2026). *Act, rest, reset, repeat*. Watkins Publishing.

Högström, P., Gericke, N., Wallin, J., & Bergman, E. (2025). Teaching socioscientific issues: A systematic review. *Science & Education, 34*(5), 3079–3122. https://doi.org/10.1007/s11191-024-00542-y

Jukes, S., Stewart, A., & Morse, M. (2021). Following lines in the landscape: Playing with a posthuman pedagogy in outdoor environmental education. *Australian Journal of Environmental Education, 38*(3–4), 345–360. https://doi.org/10.1017/aee.2021.18

Karrow, D., & Fazio, X. (2015). Curricular critique of an environmental education policy: Implications for practice. *Brock Education: A Journal of Educational Research and Practice, 24*(2), 88–108. https://doi.org/10.26522/brocked.V24I2.404

Karsgaard, C., Jin, Q., Howard, P., & Kreber, C. (2025). An ethical imperative for higher education: cultivating community partnerships in climate change teacher education. *Environmental Education Research, 32*(10), 3114–3138. https://doi.org/10.1080/13504622.2025.2588691

Kayumova, S., & Dou, R. (2022). Equity and justice in science education: Toward a pluriverse of multiple identities and onto-epistemologies. *Science Education, 106*(5), 1097–1117. https://doi.org/10.1002/sce.21750

Kim, E.-J. A. (2018). *The Relationships at play in integrating Indigenous knowledges-sciences (IK-S) in science curriculum: A case study of Saskatchewan K-12 science curriculum* (Order No. 28248733) [Doctoral dissertation, McGill University]. ProQuest Dissertations and Theses Global. https://www.proquest.com/docview/2501270857/abstract/8346278454214973PQ/1

Kim, E.-J. A., Asghar, A., & Jordan, S. (2017). A critical review of traditional ecological knowledge (TEK) in science education. *Canadian Journal of Science, Mathematics and Technology Education, 17*(4), 258–270. https://doi.org/10.1080/14926156.2017.1380866

Kimmerer, R. W. (2002). Weaving traditional ecological knowledge into biological education: A call to action. *BioScience, 52*(5), 432–438. https://doi.org/10.1641/0006-3568(2002)052[0432:WTEKIB]2.0.CO;2

Kimmerer, R. W. (2013). The fortress, the river and the garden: A new metaphor for cultivating mutualistic relationship between scientific and traditional ecological knowledge. In D. R. Longboat, K. Young, & A. Kulnieks (Eds.), *Contemporary studies in environmental and*

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Indigenous pedagogies (pp. 49–76). Sense Publishers. https://doi.org/10.1007/978-94-6209-293-8_4

Kimmerer, R. W. (2024). *The serviceberry: Abundance and reciprocity in the natural world*. Simon and Schuster.

Kovach, M. (2021). *Indigenous methodologies: Characteristics, conversations, and contexts* (2nd ed.). University of Toronto Press.

Little Bear, L. (2000). Jagged worldviews colliding. In M. Battiste (Ed.), *Reclaiming Indigenous voice and vision* (pp. 77–85). UBC Press.

Machado de Oliveira, V. (2025). *Outgrowing modernity: Navigating complexity, complicity, and collapse with accountability and compassion*. North Atlantic Books.

Malone, K. (2020). Children in the Anthropocene: How are they implicated? In A. Cutter-Mackenzie-Knowles, K. Malone, & E. Barratt Hacking (Eds.), *Research handbook on childhoodnature: Assemblages of childhood and nature research* (pp. 507–573). Springer. https://doi.org/10.1007/978-3-319-67286-1_36

Mazzocchi, F. (2008). Analyzing knowledge as part of a cultural framework: The case of traditional ecological knowledge. *Environments, 36*(2), 39–58.

McGregor, D. (2013). Anishinaabe environmental knowledge. In A. Kulnieks, D. Longboat, & K. Young (Eds.), *Contemporary studies in environmental and Indigenous pedagogies* (pp. 77–88). Sense Publishers. https://doi.org/10.1007/978-94-6209-293-8_5

McLaughlin, C., & Ruby, A. (2024). Global and national shifts in implementing educational reform: Learning across the cases. In C. McLaughlin & A. Ruby (Eds.), *Politics and knowledge shaping educational reform: Case studies from around the globe* (pp. 186–200). Cambridge University Press. https://doi.org/10.1017/9781009414753.013

Murris, K. (2022). *Karen Barad as educator*. Springer Nature Singapore. https://doi.org/10.1007/978-981-19-0144-7

Nail, T. (2023). What is new materialist aesthetics? In A. Bayley & J. Chan (Eds.), *Diffracting new materialisms* (pp. 106–166). Palgrave Macmillan.

Nayar, P. (2014). *Posthumanism.* Polity Press. https://www.wiley.com/en-us/Posthumanism-p-9780745662404

Nicholson, J., & Kurucz, E. (2019). Relational leadership for sustainability: Building an ethical framework from the moral theory of "ethics of care". *Journal of Business Ethics, 156*(1), 25–43. https://doi.org/10.1007/s10551-017-3593-4

Nxumalo, F., & Pacini-Ketchabaw, V. (2017). "Staying with the trouble" in child-insect-educator common worlds. *Environmental Education Research, 23*(10), 1414–1426. https://doi.org/10.1057/9781137453082_10

Ontario Ministry of Education. (2009). *Acting today, shaping tomorrow*. http://www.edu.gov.on.ca/curriculumcouncil/ShapeTomorrow.pdf

Ontario Ministry of Education. (2013). *The Ontario curriculum. Social studies Grades 1 to 6 history and geography Grades 7 and 8*. http://www.edu.gov.on.ca/eng/curriculum/elementary/sshg18curr2013.pdf

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Ottawa Riverkeeper. (n.d.). *The American eel*. https://ottawariverkeeper.ca/what-we-do-2/issues/endangered-species/the-american-eel/

Pacini-Ketchabaw, V., Taylor, A., & Blaise, M. (2016). Decentring the human in multispecies ethnographies. In C. Taylor & C. Hughes (Eds.), *Posthuman research practices in education* (pp. 149–167). Palgrave Macmillan.

Patterson, K., Labreche, K., Morcom, L., & St. Amant, D. (2023). Stitching together my Anishinaabe research paradigm: An approach to storytelling with Algonquin Ikwewag (women) and gender-diverse people in Mattawa and North Bay, Ontario. *International Journal of Qualitative Methods, 22*, Article 16094069231185454. https://doi.org/10.1177/16094069231185454

Pinto, L. E. (2015). Fear and loathing in neoliberalism: School leader responses to policy layers. *Journal of Educational Administration and History, 47*(2), 140–154. https://doi.org/10.1080/00220620.2015.996869

Rankin, A., Baumann, A., Downey, B., Valaitis, R., Montour, A., Mandy, P., & Bourque Bearskin, D. (2023). Two-Eyed Seeing application in research analysis: An integrative review. *International Journal of Qualitative Methods, 22*, Article 16094069231197342. https://doi.org/10.1177/16094069231197342

Rautio, P. (2013). Children who carry stones in their pockets: On autotelic material practices in everyday life. *Children's Geographies, 11*(4), 394–408. https://doi.org/10.1080/14733285.2013.812278

Riley, K., Jukes, S., & Rautio, P. (2024). Relational ontologies and multispecies worlds: Transdisciplinary possibilities for environmental education. *Australian Journal of Environmental Education, 40*(2), 95–107. https://doi.org/10.1017/aee.2024.23

Roberts, C. (2024). *Re-storying education: Decolonizing your practice using a critical lens*. Page Two.

Rosén, A. P., Salovaara, A., Botero, A., & Søndergaard, M. L. J. (2024). Introduction. In A. P. Rosén, A. Salovaara, A. Botero, & M. L. J. Søndergaard (Eds.), *More-than-human design in practice* (pp. xix–xxxi). Routledge. https://doi.org/10.4324/9781003467731-1

Rubins, M. (2019). Posthumanism reimagined: De-Westernizing perspectives on post/humanity. *Slavonic and East European Review, 97*(4), 761–772. https://doi.org/10.5699/slaveasteurorev2.97.4.0761

Sargent, L. (2021). *Shifting environmental education towards reconciliation rooted in land and relationship* [Master's portfolio, Lakehead University]. https://knowledgecommons.lakeheadu.ca/bitstreams/10d596fa-ca76-4ed4-9c42-ab8f98d5caf3/download

Shah, S. (2026). Atoms of the not-yet. *Resurgence & Ecologist, 355*. https://www.resurgence.org/magazine/article6602-atoms-of-the-not-yet.html

Schedler, A. (2023). Rethinking political polarization. *Political Science Quarterly, 138*(3), 335–359. https://doi.org/10.1093/psquar/qqad038

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 Unported License. www.ineducation.ca

Schnellert, L., Davidson, S. F., & Donovan, B. L. (2024). Educational transformation through ethical relationality in education change networks. *Curriculum Inquiry, 54*(3), 231–252. https://doi.org/10.1080/03626784.2025.2458071

Snively, G., & Corsiglia, J. (2001). Discovering Indigenous science: Implications for science education. *Science Education, 85*(1), 6–34. https://doi.org/10.1002/1098-237X(200101)85:1<6::AID-SCE3>3.0.CO;2-R

Spooner, N. (2024). An examination of educational leadership preparation in Ontario: Are principals prepared to lead equitably? *Canadian Journal of Educational Administration and Policy*, (204), 41–54. https://doi.org/10.7202/1111524ar

Stein, S. (2018). Beyond higher education as we know it: Gesturing towards decolonial horizons of possibility. *Studies in Philosophy and Education, 38*(2), 143–161. https://doi.org/10.1007/s11217-018-9622-7

Taylor, A. (2013). *Reconfiguring the natures of childhood*. Routledge. https://doi.org/10.4324/9780203582046

Taylor, A. (2017). Beyond stewardship: Common world pedagogies for the Anthropocene. *Environmental Education Research, 23*(10), 1448–1461. https://doi.org/10.1080/13504622.2017.1325452

Taylor, A., & Giugni, M. (2012). Common worlds: Reconceptualising inclusion in early childhood communities. *Contemporary Issues in Early Childhood, 13*(2), 108–119. https://doi.org/10.2304/ciec.2012.13.2.108

Tsing, A., & Bazzul, J. (2022). A feral atlas for the Anthropocene: An interview with Anna L. Tsing. In M. Wallace, J. Bazzul, M. Higgins, & S. Tolbert (Eds.), *Reimagining science education in the Anthropocene* (pp. 309–319). Palgrave Macmillan.

Tuck, E., & Yang, K. W. (2012). Decolonization is not a metaphor. *Decolonization: Indigeneity, Education & Society, 1*(1), 1–40. https://jps.library.utoronto.ca/index.php/des/article/view/18630

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The use of socioscientific issues in science lessons: A scoping review. *Sustainability, 16*(14), 5827. https://doi.org/10.3390/su16145827

Walker, K. D., Cherkowski, S., & Kutsyuruba, B. (2021). Concluding thoughts. Momentum for future striving. In B. Kutsyuruba, S. Cherkowski, & K. D. Walker (Eds.), *Leadership for flourishing in educational contexts* (pp. 315–327). Canadian Scholars.

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A Review of Rola Khishfe's (2025) *The Complexities of Socioscientific Issues in Education: Research-Based Insights and Practical Strategies*

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Rola Khishfe's (2025) *The Complexities of Socioscientific Issues in Education: Research-Based Insights and Practical Strategies* addresses an increasingly significant challenge in science education: how educators might prepare students to critically engage in scientific questioning embedded in their everyday experiences. Socioscientific issues (SSI), including climate change, vaccination, biodiversity loss, reproductive technologies, energy production, and food systems, are characterized by uncertainty and intersections among scientific evidence, ethics, politics, economics, culture, and competing social values. Khishfe (2025) positions SSI as an important context for developing scientific literacy, nature of science (NOS) understandings, argumentation, critical thinking, and informed decision-making.

The book's most immediate contribution across its eight chapters is practical. Chapter 1 establishes relationships among SSI, argumentation, and NOS; Chapter 2 explains the purpose and methodology used to construct the SSI materials; Chapters 3-6 present organized SSI cases within biology, physics, environmental science, and chemistry; Chapter 7 addresses interdisciplinary ethical and societal challenges; and Chapter 8 presents implications and recommendations. These chapters give teachers accessible starting points for classroom discussion without requiring them to develop complex SSI resources independently. The central question that weaves through this review is: How does SSI education position knowers and knowledge? Khishfe's (2025) interpretation of NOS in Chapter 1 provides a foundation for this question, describing scientific knowledge as "subjective, taking into account the scientist's background and experience" and "socially and culturally embedded" (p. 3). Reading through this lens, the book's geographical grounding in Lebanon and disciplinary organization can be understood as strengths that make SSI concrete and approachable for educators. However, the recurring use of professors as experts and the more limited engagement with local and Indigenous knowledges introduce a tension within epistemological framing. Although scientific knowledge is presented as socially and culturally embedded, the scenarios can still position epistemic authority primarily within academic institutions. For SSI pedagogy, this raises the question of how students learn not only to evaluate competing claims but also to examine how credibility is assigned to different knowers. This review argues that meaningful SSI education involves more than introducing social controversies to science content; it also creates opportunities for students to examine how knowledge claims and knowers acquire credibility.

This aspect first emerges through the book's international orientation. Khishfe (2025) constructively moves beyond the geographical dominance of North American and European contexts that characterize English-language educational resources. Chapter 5, Environmental Science, explicitly uses Lebanon, an Arabic-speaking and multilingual Middle Eastern context, as a case study and includes SSI of overfishing, water shortages, desalination, pollution, waste management, deforestation, climate change, and urbanization. This specificity is a strength because SSI are simultaneously global and local in that their consequences and possibilities are profoundly shaped by place. Likewise, Khishfe argues that "SSI integration should prioritize cultural and global relevance, with scientific themes contextualized within local and international contexts" (p. 169). Situating Chapter 5 in Lebanon, therefore, adds a regional perspective to the SSI knowledge base and demonstrates how globally shared environmental concerns acquire particular social and material meanings in place. Precisely because the book values

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contextualization, however, the prominence of Lebanon raises questions about positionality. Khishfe's affiliation with the American University of Beirut gives these examples a situated context, yet this relationship receives little explicit reflection. A positionality statement of the author could strengthen the text by identifying both the lived experiences and educational contexts informing scenario selection. With this perspective, positionality becomes epistemological rather than merely autobiographical because identifying one's relationship to knowledge production makes visible the relations among perspective, authority, power, and whose scholarship is authorized to shape dominant narratives of NOS (Stroupe et al., 2025).

A similar tension in meaningful SSI integration appears in the book's disciplinary organization. Separate chapters for biology, physics, environmental science, and chemistry make the text conveniently approachable for teachers as they can quickly locate materials relevant to their curricular areas. At the same time, many SSI are compelling because they destabilize disciplinary boundaries. For instance, nuclear energy cannot be adequately understood as simply physics, electric vehicles as chemistry, fish farming as biology, or water shortages as environmental science. Each of these SSI involves scientific, technological, environmental, economic, political, ethical, historical, and cultural considerations. Khishfe (2025) writes that socioscientific questions "demand students to weigh scientific processes against ethical, political, and social factors" (p. 169). This highlights that navigating SSI through a social justice lens requires attention both to how knowledge is warranted and to the social settings through which it is produced and used, reinforcing the need to hold epistemic and social dimensions together rather than separate by disciplinary categories (Dagher, 2020). However, the book's organization presents a practical challenge when considering how to teach SSI within existing school subjects while still making their cross-disciplinary character visible. Chapter 7 explicitly recognizes this interdisciplinarity of SSI, but it might have operated more powerfully as a principle threaded throughout the subject-specific chapters rather than primarily as a separate category.

Khishfe's (2025) treatment of argumentation is one of the book's strongest pedagogical features. The SSI scenarios generally resist directing students toward predetermined conclusions and instead ask them to construct claims, assess evidence, consider counter arguments, and defend decisions. This supports a richer conception of scientific literacy as more than knowing scientific facts. As Khishfe explains, an epistemological shift can enable students to see "scientific knowledge as a social endeavor that is subject to criticism and debate, challenging inflexible and absolute viewpoints" (p. 4). Argumentation is therefore central to the book's conception of scientific literacy. However, a concern that emerges is not that questions of credibility and expertise fall outside argumentation, nor that Khishfe (2025) neglects the social dimensions of scientific knowledge. Rather, the SSI scenarios in the book tend to foreground argumentation among positions and evidence already supplied to students, whereas citizens encountering science outside the classroom must also determine which sources, institutions, and experts warrant trust, how claims have reached them, and how the evidence has been selected and framed (Allchin & Zemplén, 2020; Sharon & Baram-Tsabari, 2020). Khishfe reports that the scenario-development process used multiple search engines, including Google Scholar and Shamaa "to reduce bias in the selection of studies" (p. 10) and that six science teachers reviewed the scenarios for content validity, language, and clarity. These procedures acknowledge the importance of SSI selection and validation of knowledge base, but they do not make the framing of the scenarios itself an object of epistemic inquiry for students. The scenarios determine which questions are asked, which evidence is available, which perspectives appear, and which actors are presented as credible. Extending Khishfe's emphasis on the social and epistemic dimensions

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of science, NOS education could therefore invite students to examine how scientific claims are selected, framed, and mediated as they circulate through society (Höttecke & Allchin, 2020). Students might then ask not only which argument is stronger, but why particular voices, evidence, and categories were included in the first place.

This concern about who is positioned as credible becomes especially visible in Khishfe's (2025) recurring use of Professor Ponso as an imagined expert across multiple chapters. In the genetically modified rice scenario, for example, students are asked, "As a scientist, do you think the Golden Rice should be produced and marketed?" and then told, "Another scientist, Professor Ponso, disagrees with your decision" (p. 154). The first prompt is pedagogically productive in that it positions learners as knowers who must inhabit scientific reasoning rather than merely receive it. The second, however, exemplifies a repeated pattern in which credible authority returns to the professor. This risks communicating an unintended epistemological lesson that expertise is located primarily in universities, even though the problem under consideration involves communities and forms of knowledge extending beyond academic science.

Farmers, fishers, healthcare workers, technicians, engineers, environmental organizations, community advocates, policymakers, and people whose lives are directly shaped by technologies or ecosystems may possess forms of expertise inaccessible to academic scientists. The book itself creates an opening for this broader conception of knowledge holders when it observes that SSI can allow students to "base their arguments on real life experiences, actively participating in social conversations about concerns and difficulties that are personal and relevant to their lives" (Khishfe, 2025, p. 5). If lived experiences of students can function as epistemic resources, the accumulated experiential knowledge of communities deserves similar consideration.

Research on local ecological knowledge illustrates why this acknowledgement of communal knowledge matters. Davis and Wagner (2003) recommend carefully identifying who qualifies as a knowledgeable local expert rather than treating either scientists or community as homogeneous categories. Oliver et al. (2012) demonstrate how farmers' knowledge can operate as expert data grounded in sustained observation and everyday land-management practice, extending what formal scientific investigations can provide. Ulicsni et al. (2019) similarly show the value of bringing conservation science into dialogue with traditional ecological knowledge and including local knowledge holders in that process. Taken together, these works suggest that local expertise should neither be romanticized or treated as automatically authoritative, nor relegated to anecdote simply because it is produced outside research institutions (Davis & Wagner, 2003; Oliver et al., 2012; Ulicsni et al., 2019).

With this contextualized understanding of communal knowledge, science educators could invite students to compare these epistemic resources by asking: What does a laboratory scientist know? What does a person who has observed an ecosystem across decades know? Through what practices was each form of knowledge produced? Where do they corroborate one another and where might they differ? This is epistemological pluralism without relativism, where relativism would mean treating competing knowledge claims as equally valid simply because they arise from different perspectives (Baghramian & Carter, 2025). On the other hand, epistemological pluralism neither abandons standards of evidence nor treats scientific, Indigenous, and local knowledge systems as interchangeable. Instead, it asks students to recognize that complex decisions may depend on multiple situated forms of knowledge and that judgments about expertise themselves require scrutiny. Broadening the range of knowers represented in SSI scenarios could, therefore, foster epistemic agency by teaching students to investigate how

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authority is constituted rather than simply receiving established hierarchies of credibility (Stroupe et al., 2025).

The comparatively brief final chapter, "Implications and Recommendations," offers useful recommendations concerning professional development, inclusive materials, curricular integration, and further research. The preceding chapters and their highlighted SSI cases, however, also generate questions about competing epistemologies, expertise, disciplinary boundaries, and teachers' responsibility for making the framing of social controversies visible. The SSI scenarios themselves repeatedly foreground uncertainty, asking students questions such as, "How certain are scientists about the knowledge related to genetically modified food?" (Khishfe, 2025, p. 155) and whether that knowledge might change in the future. This is an important strength because, as stated earlier, science is presented as dynamic rather than as a body of settled facts. Building on that strength, the final chapter could have connected uncertainty about knowledge more explicitly to questions about authority such as whose knowledge enters the discussion in the first place, and how students should evaluate different claims to expertise.

Overall, Khishfe's (2025) book makes a valuable contribution to science education. Its accessibility, geographical breadth, extensive scenarios, and emphasis on argumentation provide concrete resources for bringing consequential contemporary questions into science classrooms. If SSI education is intended to prepare learners for scientific citizenship, students must learn not only to evaluate arguments but also to interrogate disciplinary boundaries, identify appropriate expertise, recognize situated knowledge, and consider how power influences whose knowledge is heard. It offers a substantial foundation for SSI education and an invitation to push SSI pedagogy further, from considering science within social controversy toward a pluralistic examination of knowledge, power, place, and expertise. The book will be particularly useful for science teachers, teacher educators, and researchers seeking accessible, research-informed examples for integrating SSI into science education. Readers may find the SSI scenarios especially productive when used not only as resources for argumentation and decision-making, but also as starting points for examining whose knowledge is represented, how expertise is established, and which perspectives might be brought into the discussion.

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References

Allchin, D., & Zemplén, G. Á. (2020). Finding the place of argumentation in science education: Epistemics and whole science. *Science Education, 104*(5), 907–933. https://doi.org/10.1002/sce.21589

Baghramian, M., & Carter, J. A. (2025). Relativism. In E. N. Zalta & U. Nodelman (Eds.), *The Stanford encyclopedia of philosophy* (Spring 2025 ed.). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2025/entries/relativism/

Dagher, Z. R. (2020). Balancing the epistemic and social realms of science to promote nature of science for social justice. In H. A. Yacoubian & L. Hansson (Eds.), *Nature of science for social justice* (pp. 41–58). Springer. https://doi.org/10.1007/978-3-030-47260-3_3

Davis, A., & Wagner, J. R. (2003). Who knows? On the importance of identifying "experts" when researching local ecological knowledge. *Human Ecology, 31*(3), 463–489. https://doi.org/10.1023/A:1025075923297

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education, 104*(4), 641–666. https://doi.org/10.1002/sce.21575

Khishfe, R. (2025). *The complexities of socioscientific issues in education: Research-based insights and practical strategies.* Springer.

Oliver, D. M., Fish, R. D., Winter, M., Hodgson, C. J., Heathwaite, A. L., & Chadwick, D. R. (2012). Valuing local knowledge as a source of expert data: Farmer engagement and the design of decision support systems. *Environmental Modelling & Software, 36*, 76–85. https://doi.org/10.1016/j.envsoft.2011.09.013

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education, 104*(5), 873–894. https://doi.org/10.1002/sce.21581

Stroupe, D., Suárez, E., & Scipio, D. (2025). Epistemic injustice and the "Nature of Science". *Journal of Research in Science Teaching, 62*(4), 901–941. https://doi.org/10.1002/tea.21988

Ulicsni, V., Babai, D., Vadász, C., Vadász-Besnyői, V., Báldi, A., & Molnár, Z. (2019). Bridging conservation science and traditional knowledge of wild animals: The need for expert guidance and inclusion of local knowledge holders. *Ambio, 48*(7), 769–778. https://doi.org/10.1007/s13280-018-1106-z

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A Review of Cristiano B. Moura's (Ed.) (2024) *A Sociopolitical Turn in Science Education: Towards Post-Pandemic Worlds*

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Cristiano B. Moura's *A Sociopolitical Turn in Science Education: Towards Post-Pandemic Worlds* is an invitation to stay with the trouble (Haraway, 2016) of acknowledging science education's ongoing complicity in perpetuating social and ecological injustices. Readers are asked to grapple with the consequences of the COVID-19 pandemic for science education while recognizing that oppression in its many forms continues to inflict both quick and slow violence on our most vulnerable communities, as claimed by Sharma and Kalyanaraman in Chapter 3. As Moura comments early in the book, not everyone experienced the COVID-19 pandemic in the same way. Among other factors, injustices relating to racism, socioeconomic status, and geography are exacerbated, not created, by major disturbances like this pandemic (Alsop & Bencze, 2020). This edited volume confronts the ways in which science continues to be shaped by neoliberal, colonial, and capitalist forces, calling for the dismantling of these systems while offering new perspectives for turning towards social and ecological justice. Across 19 chapters, 35 contributing authors transport readers to geographically diverse contexts. They join hands in solidarity to articulate and advocate for a sociopolitical movement in science education that boldly re-imagines a more just future for the human and more-than-human worlds.

The book is organized into four parts with the first consisting solely of the editor's introduction. Moura provides a useful roadmap outlining each chapter and a rationale for the book's organization, adeptly situating the book within the post-pandemic context of collective—yet disparate—suffering. Importantly, the introduction distinguishes the sociocultural and sociopolitical turns in science education scholarship. Characterized by power, identities and ontologies, the sociopolitical turn moves beyond understanding culture towards transforming and dismantling oppressive structures. The second section (Chapters 2–5) then lays the foundation by introducing theoretical concepts. The takeaway is that a sociopolitical framing is needed for a vision of scientific literacy in the Anthropocene that is more equitable and less violent for our socioecological systems. Possible approaches discussed by authors include didaktik models, slow pedagogies, critical place-based pedagogies, and valuing Indigenous and land-based knowledges. Readers are urged to (re)consider human's exploitative relationships with Land by re-examining how we, as humans, might learn not only *about*, but *with* and *through* our more-than-human kin.

Diverse stories and perspectives from global contexts are featured in Section Three (Chapters 6–13). Across these chapters, authors continue challenging the Western Science hegemony that views science as objective, neutral, apolitical, and universal, reminding us that science is also emotional, embodied, spiritual, and co-constructed. Authors emphasize the importance of recognizing dominant science norms, enacting culturally relevant pedagogies, and understanding diverse knowledge systems to facilitate dialogue and cultural border crossings. Weinstein and Schafer's Chapter 7 stands out for its narratives bearing "[witness] to the suffering wrought by the 'torquing' that youth and teachers must do to survive in binary sex/gender categories" (p. 138). Their stories situate this chapter against the backdrop of a pandemic while illustrating why recommendations for queer-friendly science classrooms urgently need attending to amidst the rise of right-wing populism. Section Three also draws attention to online teacher training and digital strategies leveraged by museums to engage the public, suggesting that the sociopolitical movement need not be restricted to in-person or formal school environments.

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In the fourth and final section, Chapters 14–19 play with ideas for a re-imagined science education in a post-pandemic future. Authors describe this future as one where nature-culture, affect-cognition, and art-science binaries are disrupted. In this future, pluriversal science approaches are made familiar rather than strange (Fifield & Letts, 2014). As Lima and Martins assert in Chapter 19, the purpose of such an education is "to promote life, justice and plurality … [to] empower individuals, enhancing their strength and ability to act" (pp. 362–363). They ask science educators to consider the interconnectedness inseparable from Afro-diasporic cosmovisions. Nascimento, Ferreira, and Moura similarly invite us to understand and value diverse ontologies like perspectivism and multinaturalism for thinking differently about nature and culture in Chapter 17. Other authors, like Bazzul in Chapter 15, ask what it would mean for researchers, teachers, and students to collectively engage in acts of citizenship rooted in understandings of science-power entanglements. Bazzul contributes a Canadian and prairie perspective to the book by providing commentary on resistance to public health mandates from the 'freedom convoy' and white conservative communities. Drawing on the work of anthropologist Anna Tsing, this chapter reminds us that these relationships are what give meaning to the pandemic because "[t]*he pandemic, in itself, has very little significance*" (p. 298, emphasis in original); educators must take seriously the sociopolitical and historical contexts that are wrapped up with/in science.

By organizing the chapters into sections focused on theorizing foundational concepts of the sociopolitical turn, exploring diverse local experiences, and reimagining possibilities, the editor, Moura, succeeds in tracing a narrative for science education that maps its past, present and future. Despite their different emphases, the curated chapters are collectively united in their commitment to the sociopolitical turn. Bringing international experiences together is another strength of this book. Readers have opportunities to engage with scholarship from 13 countries across the Americas, the Caribbean, Europe, and Oceania. The book transcends not only geographical boundaries, but also those of physical classrooms. We learn about glaciers in a national park in Torres Olave and Guerrero's Chapter 5, about public health from science museums in Navas Iannini and Pedretti's Chapter 8, and even from dancing around a metaphorical bonfire in Lima and Martins's Chapter 19.

The target audience for this theoretically dense book is clearly science education researchers. However, as a scholar-practitioner, I find it worthwhile to highlight a few tangible examples from the chapters that provide inspiration for how science educators might enact pedagogies aligned with the sociopolitical turn. Gandolfi's Chapter 4 provides sample teaching sequences for two socioscientific issues originally used with middle-years students: tantalum and niobium mining and preservation of biodiversity. In these activities, learners are invited to discuss environmental and social issues relating to metal extraction and consider the impacts of a proposed macaw nature reserve. Dumrauf et al.'s Chapter 10 outlines the content and activities of their online science course. Although their chapter is situated in Argentina, themes like nutrition and food or health and vector-borne diseases can certainly be adapted for different contexts. In Chapter 11, Robles-Piñeros and Abella offer an example of how the dimensions of an Intercultural Science Education Curriculum with sociopolitical commitments could inform a biology course. A useful table is provided to show how various natural phenomena and potential action projects intersect with their framework.

My primary critique of this book centers on each chapter's treatment of the post-pandemic context. While the chapters are all relevant to the sociopolitical turn and associated

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period, they are inconsistent in foregrounding the pandemic context itself. In Chapters 8 and 10, which discuss online engagement with educators and the public in direct response to COVID-19, the pandemic connection is self-evident. Some chapters also situate their theoretical discussions in close conversation with the pandemic. Chapter 15, which explores self-disclosure through the relationship between religious confessionals and vaccine mandates, is one such example. Conversely, other chapters, including but not limited to Chapter 2, present excellent discussions of visions for scientific literacy in the Anthropocene but only superficially mention the post-pandemic. Consistent weaving of the pandemic throughout all chapters would have strengthened the book because this context is what makes Moura's volume especially compelling in relation to other science education books on social justice and the Anthropocene, such as *Nature of Science for Social Justice* (Yacoubian & Hansson, 2021) and *Reimagining Science Education in the Anthropocene* (Wallace et al., 2022). Explicitly centering the pandemic throughout all chapters would have further distinguished Moura's book from others in the field.

The way Indigenous knowledge systems are discussed in Chapter 12 is another critique. It matters what words we use to talk about these knowledges because, as evident in Jacobs (2025), Indigenous peoples from around the world hold deep scientific wisdom. Although Nazir's Chapter 12 advocates for cultural border crossings, it subsumes Indigenous ways of knowing into "alternative knowledges" (p. 249) and positions them in opposition to "scientific theories" (p. 249). This inadvertently construes Indigenous knowledges as 'not science.' Also problematic is how the term Indigenous knowledges is conflated with religion and magic in this chapter. As Snively and Corsiglia (2016) have discussed, spirituality is inseparable from Indigenous knowledge systems and not synonymous with religion as understood from a Western lens. Rather, "spirituality means life with consciousness … the land, the plants and animals, and people all have their own spirit, integrity, and substance; they must be respected" (p. 89). These issues in Chapter 12 could be addressed by more carefully differentiating between terms and concepts, as well as clarifying whose knowledge systems are considered Indigenous in a multiethnic Trinidad and Tobago context, where this chapter is situated. Spirituality with/in science education demands further consideration in the post-pandemic era. As Tolbert and Azarmandi remark in Chapter 13, "a strident secularism in the sciences has been used to render 'less than' those knowledge systems, such as many Indigenous knowledge systems, in which spirituality is entangled—with detrimental effects" (p. 258).

Overall, Moura's (2024) book makes a valuable contribution to science education scholarship by exploring how ongoing social and ecological injustices intersect with major disturbances like the COVID-19 pandemic. Though the pandemic context could be more explicit in places, the volume provides a timely and unique lens for *in education* readers to consider the sociopolitical turn in science education. I recommend this book primarily to science education researchers, though practicing K–12 educators could also draw insights from the text. This book calls on science educators to join the sociopolitical movement so that the brave will no longer be the "few, inhabiting the margins of a tiny field" (p. 18). If nothing else, readers can take Moura's key message as the editor: Educators have the privilege, power, and agency to "create new worlds in science education capable of forging eco-just futures" (p. 18). Let us interrogate hegemonic science norms and become interlocutors between diverse science knowledge systems. With the hopeful, dreaming hearts described by Higgins and Sanchez in Chapter 16, let us give meaning to this post-pandemic moment by honouring our ethical response-abilities for the planet.

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References

Alsop, S., & Bencze, L. (2020). Editorial: Reimagining science and technology education in the COVID-19 portal. *Journal for Activist Science & Technology Education*, *11*(2), i–vii. https://doi.org/10.33137/jaste.v11i2.34530

Fifield, S., & Letts, W. (2014). [Re]considering queer theories and science education. *Cultural Studies of Science Education*, *9*, 393–407. https://doi.org/10.1007/s11422-013-9509-4

Haraway, D. J. (2016). *Staying with the trouble: Making kin in the Chthulucene.* Duke University Press. https://doi.org/10.1215/9780822373780

Jacobs, L. A. (Ed.). (2025). *Indigenous critical reflections on traditional ecological knowledge.* Oregon State University Press.

Moura, C. B. (Ed.). (2024). *A sociopolitical turn in science education: Towards post-pandemic worlds.* Springer. https://doi.org/10.1007/978-3-031-78586-3

Snively, G., & Corsiglia, J. (2016). Indigenous Science: Proven, practical and timeless. In G. Snively & W. L. Williams (Eds.), *Knowing home: Braiding Indigenous Science with Western Science* (Vol. 1, pp. 80–93). University of Victoria. https://pressbooks.bccampus.ca/knowinghome/chapter/chapter-6/

Wallace, M. F., Bazzul, J., Higgins, M., & Tolbert, S. (Eds.). (2022). *Reimagining science education in the Anthropocene.* Palgrave Macmillan. https://doi.org/10.1007/978-3-030-79622-8

Yacoubian, H. A., & Hansson, L. (Eds.). (2021). *Nature of science for social justice.* Springer. https://doi.org/10.1007/978-3-030-47260-3

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Puvithira Balasubramaniam is a PhD student in the Faculty of Education at the University of Manitoba in Winnipeg, located on Treaty One Territory and homeland of the National Red River Métis. As a first-generation Tamil-Canadian student, science educator, and researcher, she engages with narrative inquiry to critically explore how Tamil-Canadian students navigate and negotiate their hyphenated identities and worlds, particularly within science education. Puvithira's research aims to emphasize embracing a pluralistic society through critical approaches centering decoloniality, intersectionality, relationality, and ongoing self-reflexivity.

G. Michael Bowen, PhD, has taught science in public and private schools from Grades 5 to 13 in both rural and urban settings. He has degrees in science, journalism, sociology, and education which inform his work as an associate professor at Mount Saint Vincent University (Halifax, Nova Scotia). His university teaching includes science/STEM education methods, research methods, curriculum theory, identity theory, critical media literacy, environmental education, and action research. His research interests include enculturation to science practices (inquiry, graphical and data literacy), news/entertainment media and science/education, and science fairs. His current research is on the use of STEM technologies with young children, AI and (science) education, and citizen science project participation.

Carol Brown, PhD, is an assistant professor of Secondary Science Education at the University of Alberta. Carol has recently completed her PhD in Secondary Education (degree conferral: November 2026) and possesses an MEd, BEd, and BSc. Carol has worked as a high school science teacher in Alberta and New Brunswick, as well as a sessional instructor and educational developer in post-secondary contexts. Carol's research interests relate to how science education in formal (e.g., K-12 and post-secondary) and informal (e.g., libraries, science centres, social media campaigns) contexts can respond to science and health misinformation.

Frank Deer, PhD, is a professor in the Faculty of Education of the University of Manitoba. Frank is Kanienkeha'ka from Kahnawake, a community that lies just south of Tiotia'ke in the eastern region of the Rotinonshón:ni Confederacy. Frank earned a PhD in Educational Administration from the University of Saskatchewan. Frank studies Indigenous language education and Indigenous religious and spiritual orientations in schools. Frank has previously served as a classroom teacher in Northern Manitoba and in the Inner City of Winnipeg.

Steffie Dmello is a PhD candidate and part-time professor in the Faculty of Education at the University of Ottawa. She was born in India and has a background in Zoology (BSc., MSc.) and Education (BEd, MEd). Her research focuses on exploring the relational dynamics between children and more-than-humans by employing diverse methodologies such as multispecies ethnography. She aims to challenge the dualistic perspectives in education by emphasizing the interconnectedness of humans and more-than-humans.

Norris Igbinosa Erhabor, PhD, is a senior lecturer at the University of Benin, Nigeria, and an internationally engaged researcher in environmental and science education. His interdisciplinary research spans environmental sustainability, climate change adaptation, conservation behaviour, environmental psychology, and innovative low-cost learning solutions. He has received competitive international funding and fellowships, including the Open AIR Queen Elizabeth

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Scholars Award, International Council for Canadian Studies Award, British Ecological Society Grant, amongst others. His work connects research, education, and community action, with extensive experience in international collaboration, grant development, and translating evidence into practical solutions for sustainability and environmental challenges.

Xavier Fazio, EdD, is a professor of education in the Department of Educational Studies at Brock University and an affiliate member of the Environmental Sustainability Research Centre. His research focuses on science and environmental sustainability education, teacher education and development, STEM curriculum and assessment, and complexity and systems thinking. He collaborates with international research partners and has received funding from SSHRC and other government and nonprofit agencies. Dr. Fazio recently led a multi-year SSHRC Insight Grant on Science Education and Local Communities and served as an associate editor of the Journal of Science Teacher Education.

Emily Krushelnycky is a PhD student, sessional instructor in the Department of Educational Studies at Brock University, research assistant, and occasional elementary teacher. Her research explores socioscientific issues in education at the elementary (K–5) level, child development, science education, and learning theory. Drawing on both academic and practical experience, Emily's work contributes to educational discourse by examining the ways in which young learners engage with complex scientific and societal issues, and how development theory can inform classroom practice.

Michelle Leonard is a settler scholar and PhD candidate in the Faculty of Education at the University of Ottawa. With a background in Western science (BSc, MSc), her current research explores how youth and adults in informal outdoor education settings story their relationships with the natural and more-than-human world, and how Indigenous storywork can expand this understanding of kinship and help re-story relationship with the more-than-human world.

Floriane Lévéder is a PhD candidate, teacher and part-time professor. She was born in France and has a background in political sciences (BPol) and education (BEd, MEd). Her research seeks to move beyond a simplified policy-practice gap in socioscientific issues education through innovative multi-case studies grounded in ecological and complexity thinking, recognizing professional learning as a complex, 'wicked' problem that resists simple solutions.

Peiki Loay holds an MEd from the Faculty of Education at the University of Manitoba. She is also a science educator in the Manitoba public school system. Her research interests include justice-oriented science pedagogies, Indigenous science perspectives, the role of science educators in reconciliation, queering science through wonder, anti-racism and (re)centring marginalized voices through (counter)storytelling. As a teacher and scholar, Peiki walks alongside educators locally and provincially in the areas of treaty and critical social justice to foster courageous, accountable spaces of belonging for all learners.

Lilian Pozzer, PhD, a co-editor of this special issue, is an associate professor and Department Head in Curriculum, Teaching and Learning at the University of Manitoba. Lilian has extensive experience with multimodal microanalysis of interaction and communication in science classrooms, gesture-speech integration and visual representations (inscriptions) in science teaching and learning, and curriculum analyses. Lilian is interested in sociocultural studies in science education and the rethinking, restructuring, and reenactment of inter- and intra-species relations as

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they apply to teaching, learning, and research in science education for social and environmental justice.

Latika Raisinghani, PhD, a co-editor of this special issue, is an assistant professor with the University of Winnipeg and an adjunct professor with the University of Manitoba. Her interdisciplinary research and teaching focuses on culturally responsive science and mathematics education, critical analysis of curriculum, instruction and assessment, and understanding the nature of science. Latika's current research projects explore teachers' perspectives of new science curriculum and the impact of instructional language on science teaching in Manitoba. She is an active member of the Science Education Research Group of Canada, an active reviewer for various educational journals, an editorial board member of the *Australian Journal of Environmental Education*, and a consulting editor for *in education.*

Giuliano Reis, PhD, is an associate professor at the University of Ottawa's Faculty of Education. His research focuses broadly on the intersection of science and environmental education. His publications include *International Perspectives on the Theory and Practice of Environmental Education: A Reader* (Springer, 2018), *Sociocultural Perspectives on Youth Ethical Consumerism* (Springer, 2018), and *Ethics in Science Education: Theoretical and Actionable Paths for Meaningful Transformations* (Springer, 2027). He is married to Juliana Reis and together they have two daughters: Ana-Julia and Maria-Luiza Reis. He is also the grandfather of little Sofia.

Erin Sperling, PhD, is an Ontario certified teacher and an assistant professor in the Faculty of Education at Wilfrid Laurier University in Ontario. She is a settler and a guest on Turtle Island. Her doctorate in curriculum studies and teacher development was received from the Ontario Institute for Studies in Education at the University of Toronto, where she focused on food justice from an ecojustice lens in community-based learning. She has been a classroom teacher in Ontario, England, and Tanzania. Her research supports learning in and about science and environmental and climate justice education for teacher education, through citizen science, and place-based formal and informal learning, with reconciliation in mind and heart.

Ellen Watson, PhD, a co-editor of this special issue, is an associate professor at Brandon University's Faculty of Education. Her research interests center on teachers' beliefs about science, epistemic education in science, physics education, and teacher advocacy. Her recent work has focused on teachers' beliefs about science knowledge and on investigating those experiences teachers' attribute as impactful on their belief development. She is an active teacher in—and current Department Chair of—the Curriculum & Pedagogy Department and teaches courses in science education, curriculum studies, and pedagogy.

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