Toward a more relevant and responsive science education in schools: Science education for socially responsible and critical future citizens

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Abstract

Toward a More Relevant and Responsive Science Education in Schools: Science Education for Socially Responsible and Critical Future Citizens

Nour Maita

The time of uncertainty and risk we live in today demands future citizens capable and willing to make transformative changes that strengthen human values, equality, and justice on Earth. For education in general and science education in particular, the COVID-19 pandemic has created new realities that require shifting science teaching and learning away from traditional approaches that focus on content memorization and teach science as depoliticized and decontextualized. In this thesis, I analyze the theory of learning and experience of John Dewey, the theory of problem-posing pedagogy of Paulo Freire, and the theory and practice of socioscientific issues to examine their contributions to transforming science education in the middle school towards a more relevant and responsive framework. I argue that activating a science teaching and learning context through the lens of these theories improves students' understanding of the nature of science and empowers them to recognize the interrelation of science with social, political, economic, cultural, ethical, and environmental factors. Additionally, it promotes the development of students' critical thinking and social responsibility to engage with awareness in decision-making processes concerned with science-related social and environmental dilemmas. The significance of my thesis lies on the importance of the theoretical contributions to strengthen a critical scientific literacy, a politicized science education that involves a socioscientific issues framework to foster a science educational culture that nurtures critical and responsible future citizens. Implications, recommendations for teachers, and challenges in practice are also discussed.

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Finally, I express my deep love and gratitude to my kids, Omar, Celine, and Mariam and to my Mother and Father for their continued prayers.

Dedication

I would like to dedicate this thesis to my husband, Khoder and my children, Omar, Celine, and Mariam.

Table of Contents

List of Figures

Chapter One- Introduction, Personal Interest, Problem Statement and Research Assumptions

Introduction

Reflecting on the contemporary COVID-19 pandemic that is dramatically influencing every part of the world and each aspect of our lives, I find it clearly evident how communications with the public on the media, social media platforms and different websites use science and scientific discourse to serve multidimensional agendas; to inform people about ways of transmission and prevention of the novel Coronavirus and its variants, to encourage consumerism through advertisements of sanitization products and masks, to demonstrate global competitions regarding vaccines, to maintain public trust in the effectiveness of the produced vaccines and most importantly to govern individuals' behaviors as a means for self and other protection. It is also apparent how politicians use scientific discourse to achieve politically driven agendas, especially in the past 2020 USA elections. As mentioned in *The Washington Post*, politics not only contaminated the scientific process, but it also created an epidemic of distrust between science and the public which "undermines the nation's already chaotic and ineffective response to coronavirus" (Achenbach & McGinley, 2020, para. 3).

In my opinion, this distrust is also a consequence of the public's lack of scientific literacy and critical thinking skills to understand how science is produced and used, consider the reliability and accuracy of data resources, and distinguish between scientific information, misinformation, and disinformation. Tremendous loads of information are available for the public to research about the COVID-19 pandemic. Still, many people use social media as their primary source of information (Hottecke & Allchin, 2020). However, fake news, misconceptions, and bias accompany many posts and public discussions on social media, influencing how people view science and make decisions regarding science-related challenges and social issues.

In addition to the COVID-19 pandemic, the world suffers from many dilemmas like climate change, water scarcity, food insecurity, global health issues, and loss of biodiversity. These global challenges interrelate science with society and the environment and pertain to politics, social justice, and inequality. They constitute diverse socioscientific issues that form so-called Big Questions for the science community and the public. Additionally, they can activate a relevant and responsive science educational context for students to develop conceptual understanding about science and critically engage with science debates and discussions. Understanding the multidimensional aspect of science and technology-related social and environmental dilemmas and participating in decision-making processes to resolve local and global issues require a cooperative and reliable endeavor between science and an informed citizenry. By *informed citizenry*, I refer to Giroux (2011) to define the term as active citizens "who are critical, self-reflective, knowledgeable and willing to make moral judgments and act in a socially responsible way" (p. 8). The time of uncertainty and risk we live in today demands future citizens capable and willing to make transformative changes that strengthen human values, equality, and justice on Earth.

For education in general and science education in particular, the COVID-19 pandemic has created new realities that call for a paradigm shift in science teaching and learning and emphasize the need to promote learners' scientific literacy and critical thinking. The sudden and unprepared transition to online learning revealed the oppression maintained in the educational system, especially in science education. Schools still adopt traditional approaches that perpetuate the view of science as "a straight-forward, logical, empirical and reliable enterprise" (Dillon &

Avraamidou, 2020, p. 2), and teach science as depoliticized and decontextualized. However, many reasons within our current situation emphasize the importance of better understanding science including: the chaotic response to the COVID-19 pandemic; the negative and positive public attitudes towards science; the public's limited scientific literacy; and insufficient crisis communication. The COVID-19 pandemic offers opportunities for educators and learners to recognize how economic systems and socio-political contexts influence the processes of learning and practicing of science and rethink these processes through a social justice sense (Dillon & Avraamidou, 2020). Recognizing these opportunities is necessary to develop future citizens with a 'science identity' that allows critical engagement in science to promote appropriate decision-making and make the world a better living place (Barton et al., 2011).

Instilling learners with the necessary knowledge and skills that promote scientific literacy, critical thinking, and critical awareness about reality empowers them to act as "critical consumers of scientific knowledge" (Osborne & Dillon, 2008, p. 8). Students need to develop open-mindedness and reflective thinking to examine multiple perspectives, evaluate scientific data, and differentiate between scientific information and misinformation. Consequently, they can realize sociological ways of thinking and question human practices (Reiss, 2020) to make appropriate judgments about issues underpinned by scientific knowledge or technological capability while considering the moral, political, and social dimensions (Hodson, 2003).

As Hodson (2003) states, citizens should not be content with the role of "armchair critic" (p. 645). Instead, they need to consider and recognize how "science and technology are impacted by, and impact upon, the physical and the sociopolitical environment" to practice their rights within a democratic and technology-driven society (p. 650). I believe that achieving this goal requires the activation of a humanistic, inclusive, and responsive science teaching and learning environment that engages students in contextualized, relevant, dialogical, and reflective learning experiences. It also demands that educators understand the nature of science and critically reflect on their views about science and their pedagogical practice to trigger a perspective change in the way science is viewed and used as part of our daily lives.

In this thesis, I analyze three theories: Dewey's Theory of Experience; Freire's Theory of Problem-Posing Education; and the theory and practice of socioscientific issues to examine their contributions to transforming science education in school into a more relevant, contextualized, and humanistic teaching and learning practice. My focus is on middle school, mainly grades seven, eight, and nine. I chose middle school for three reasons. First, my experience as a Chemistry and Biology teacher resides primarily in grades seven and eight. Second, middle school reflects a critical developmental stage for students in their adolescence years as they begin to think of themselves as adults becoming more autonomous and responsible (Eccles, 1999). Many biological, cognitive, behavioral, and social changes accompany children in their adolescence, and all have a prominent role in the way they establish their self-identity, self-consciousness, relation with their community, and sense of responsibility (Eccles, 1999). Third, several studies show that a clear feature of science education research is the decline in students' attitudes and interest in school science as students progress through middle and secondary levels (Osborne et al., 2003; Barmby et al. 2008; Gottfried et al. (2009); Potvin & Hasni 2014). Accordingly, the science teaching and learning environment within its pedagogical approaches and social relationships must be inclusive and responsive to students' needs and social context to enhance students' conceptual understanding and learning motivation and to help them develop critical thinking and a socially responsible character.

My Personal Interest

In the middle of this Pandemic Era, I question the role and position of science education in schools, mainly its contributions to fostering a future generation that strengthens human values and justice. As a science educator, I reflect on the educational practice of school science, and I encourage educators to raise these questions and reflect on their teaching beliefs and practice to transform science education.

1- What skills does the traditional textbook-centered and teacher-centered science education add to a student's life, as a member of a community living in and with the world, beyond learning scientific concepts, laws, and facts? Here, I recall Dewey's (1910) emphasis that science education in schools should include social and moral dimensions. Teaching science as a "ready-made material" rather than acknowledging it as a process of metacognition is insufficient (Dewey, 1910). Are we also focusing on developing students' personal, social, ethical, cooperative, communicative, creative, and attitudinal skills?
2- How can students make-meaning of science and use science to engage actively and critically in discussions and debates regarding socioscientific issues influencing their lives?
3- How can we bridge the gap between school and out of school science?
4- How can educational theories inform the science education practices to help students develop a critical, responsible, and change-oriented mindset that can foster the common good of humanity and maintain environmental sustainability?

5- How can science education be a gateway to raise students' awareness of their rights as citizens in a democracy and of the oppression and inequality masked by the bright side of technological advancements?

My experience as a student and as a middle school science educator in the Middle East reflects a culture of oppression that limits students' opportunities to achieve genuine human liberation. Science education is approached with "an ideology of neutrality," which gives little space to teaching through inquiry and encourages passivity in learning (Jenlink & Jenlink, 2019, p. 156). The 'banking' model of education (Freire, 2000) dominates in the science classrooms despite the efforts to apply active approaches, including hands-on, experiential, and blended learning strategies. Science teaching is mainly limited to memorizing scientific concepts and facts and using textbook-driven science practices and assessments. Within this context, the space for pedagogical approaches that engage students in discussions, argumentation, and authentic dialogue to develop scientific literacy and critical thinking is narrow, given that both are essential for learners to act responsibly in a world dramatically influenced by science and technology.

The impact of the neoliberal hegemony on the educational system has shifted the focus of educational institutions towards increased performativity and accountability to comply with the demands of the global economy. Accordingly, teachers feel pressured to overemphasize the standardized content and disregard discussions and dialogue about controversial social issues that involve the integration of science concepts and processes. The main goal becomes teaching that ensures students' success in science assessments rather than achieving the multidimensional level of scientific literacy needed to act responsibly within society (Bybee, 1997). What knowledge is constructed, in whose favor, how knowledge can be situated and applied in reality are rarely investigated questions as long as students achieve good marks. This is especially the case for science teaching in middle school. Students are prepared for the official Lebanese exams similar to Canada's high-stakes testing, performed at the end of the academic year of grade 9. Teaching science in Grades Seven and Eight becomes a preparatory stage regarding skills and concepts to pass Grade Nine examinations. This context of science education places the teachers and the textbook content at the center of learning and treats students as passive receptacles of knowledge (Freire, 2000). It limits understanding of content to the perspective of the scientist, mainly Western views, in addition to the teacher's beliefs and excludes the learner's or society's perspective.

Additionally, science teaching and learning is framed by an epistemology of positivism that objectifies students and presents knowledge as instrumental and "divorced from the political and cultural traditions that give it meaning" (Giroux, 2011, p. 89). Giroux (2011) explained how teaching within a 'culture of positivism' leaves students "with little reason to generate their own meanings, to capitalize on their own cultural capital, or to participate in evaluating their own classroom experience" (pp. 97-98). In the science classroom, it restricts questioning the relevance of the constructed knowledge and the influence of the implemented curriculum on students' perceptions about the nature of science and how science contributes to their own lives as active citizens.

Within this pedagogical approach, the dominant vision of scientific literacy is Vision I (Roberts, 2007a) that focuses on literacy "within science" (p. 730). Roberts (2007a) provided a synthesis of the different perspectives and definitions of scientific literacy, and he identified two conflicting visions-Vision I and Vision II- which demonstrate different philosophies and opposing interests that shape the content of the science curriculum in schools. Vision I is scientist centered and involves a decontextualized science subject matter (Aikenhead, 2007). It "looks inward" at science, its products as laws and theories, and its processes as hypothesizing and experimenting (Roberts, 2007b, p. 9). In contrast, Vision II focuses on literacy about science-related issues in which considerations other than scientific knowledge and facts are included in science teaching and learning. It "looks outwards" at science which means contexts in which science has a role, such as decision-making about socioscientific issues (Roberts, 2007b, p. 9).

Problem Statement

It is common for science teachers to address different socioscientific issues such as climate change, genetically modified products, extinction, and other topics through Big Questions to achieve specific curricular objectives and meet assessment standards and questioning criteria. Science teaching here is mostly limited to transmitting a predetermined package of scientific facts and concepts to students. It focuses on results without giving students the space to evaluate how scientific knowledge was constructed (Chen et al., 2019). Accordingly, students are taught within a positivist view of science which limits opportunities for critical inquiry. Instead, students need to engage in educative learning experiences that involve the cognitive and the social, political, moral, and contextual dimensions of learning. These educative experiences are fundamental to helping students acquire knowledge, thinking skills, and attitudes that promote the appropriate level of scientific literacy, critical thinking, and character development.

In my thesis, I examine John Dewey's Theory of Learning and Experience, Paulo Freire's Theory of Problem-Posing Education, and theory and practice of socioscientific issues to examine their contributions to transforming science education. I aim to illuminate how the philosophical and practical frameworks mentioned above can transform the prevailing science teaching and learning culture in middle school to promote students' learning through reflection on their reality and active engagement in society. I argue that creating a science teaching and learning environment that incorporates elements of these theories into the teaching and learning of science would shift science education from the traditional and mechanistic value-free approach that is content led to a more humanizing and relevant approach that contributes to students' intellectual and responsible character development. I think that it will be too much to examine curricula at this stage. My recommendations imply making changes to science teaching and learning in terms of pedagogical practice and student-teacher relationship to engage students in a socially relevant context that embraces human values and responsible citizenship as essential elements of learning and action. Fostering learners' awareness towards having a proper understanding of the nature of science and the role of science in society in addition to their role as responsible citizens entails a science pedagogical approach that is relevant and responsive to students' realities and needs.

Research Question

What are the contributions of John Dewey's Theory of Learning, Paulo Freire's Theory of Problem-Posing Education, and theory and practice of socioscientific issues that can make the science pedagogical practice in middle school more contextualized, relevant, and responsive to students' reality?

The Assumptions behind this Research

The first assumption relates to the dominant culture of school science education. According to Osborne (2007), the dominant culture of science education worldwide rests on a "set of values" that causes students' negative attitudes towards science (p. 176).

Osborne (2007) identifies seven fallacies that characterize the cultural norms of science education which are; 1) the foundational fallacy, 2) the fallacy of coverage, 3) the fallacy of a detached science, 4) the fallacy of critical thinking, 5) the fallacy of the scientific method, 6) the fallacy of utility and 7) the homogeneous fallacy. These fallacies influenced my view of science and my experience as a learner in school, a biology student in university and a middle school science teacher. In Figure 1, I clarify the meaning of each fallacy in the science educational practice as explained by Osborne (2007).

The second assumption relates to the diverse and multifaceted meanings of scientific literacy. It highlights the need to adopt a holistic vision when conceptualizing scientific literacy to activate a science teaching and learning framework that improves students' understanding of the nature of science. Understanding the nature of science improves one's understanding of the epistemology of science, which positively influences how content knowledge and informal reasoning are applied when responding to socioscientific issues (Sadler, 2004a). Throughout my learning and teaching experience, I rarely had the opportunity to deeply explore the notion of the nature of science (NOS) until I decided to write my thesis. One reason is that research literature about this area is mainly centered in Europe and the USA (Rannikmae, Rannikmae & Holbrook, 2006). Additionally, there is little space for students to actively learn about the NOS in my background culture. For Sadler (2004a), the NOS reflects a basic description of the scientific enterprise to help non-scientists understand the field's strengths and limitations. It refers to the epistemology of science, science as a way of knowing, and the values and beliefs inherent to scientific knowledge and its development (Abd-El-Khalick & Lederman, 2000). There isn't any specific or single definition about NOS given the multifaceted, complex, and dynamic nature of the scientific enterprise, but there is an acceptable level of agreement emphasizing the general aspects of NOS (Abd-El-Khalick, 2005).

According to Abd El Khalick (2005), the general aspects of NOS characterize scientific knowledge as a) tentative (i.e., subject to change), b) empirical (i.e., based on and/or derived from observations of the natural world), c) theory-laden, d) partly the product of human inference, imagination, and creativity (i.e., involving the invention of concepts and imagination), and e) socially and culturally embedded. Additionally, two more aspects are “the distinction between observation and inference, and the functions of, and relationship between scientific theories and laws” (p. 17). The nature of science education integrates nature of science with educational goals that aim for character and social development to empower students to develop intellectual capabilities, social skills, and ethical and moral values that enable them to act as responsible citizens within society (Roth & Lee, 2004).

The third assumption relates to the importance of developing students' critical thinking through science education to establish goals of freedom and democracy. Critical thinking is strongly related to science education (Santos, 2017), but the field lacks a "coherent and defensible conception" about the nature of critical thinking in terms of process and skills (Bailin, 2002, p. 361). In a review of the role of critical thinking in science education, Santos (2017), citing peer-reviewed literature, reveals challenges to implementing critical thinking in science education. These challenges are due to teachers' insufficient knowledge about the meaning of critical thinking, inconsistencies about critical thinking dispositions, lack of training, guidelines and experience regarding methods that foster reflective and critical thinking, and teachers’ main focus on teaching content with critical thinking being a secondary aim in the teaching and learning practice (Santos, 2017).

The fourth assumption relates to the importance of teaching science relevant to students' lives. Relevance is a multifaceted and multidimensional concept in science education that mainly reflects the meaningfulness of science and its positive consequences for learners at a personal, societal, and vocational level (Stuckey et al., 2013). The teaching and learning context of the discipline-oriented science curricula leads to a lack of relevance in science education and consequently decreased interest in science (Gilbert, 2006). Traditional science curricula are fragmented and crammed and science education "is one that is dominated by a conduit metaphor, where knowledge is seen as a commodity to be transmitted" (Osborne & Dillon, 2008, p. 9). Students' learning is mostly oriented to knowledge acquisition, and there are limited opportunities to develop social skills and social responsibility. To increase the relevance of science, a humanistic and value-centered science learning approach that involves socioscientific issues is suggested to enhance students' understanding of the interrelationship between science and society (Marks & Eilks, 2009). Accordingly, students can acquire knowledge and skills that increase their self-awareness and empower them to participate in controversial science related societal debates and decision-making processes (Stuckey et al., 2013).

Organization of the Paper

This thesis includes five chapters. In the first chapter, I provided the reader with some background about problems in science education and reflected on my personal experience to explain the need to transform the science educational practice in school, with the main focus being middle school.

In the second chapter, I describe the different visions that underpin the concept of scientific literacy, and I explain the need for implementing a science teaching and learning framework that advocates for Vision III or critical scientific literacy.

In the third chapter, I analyze John Dewey's Theory of Learning and Experience and Paulo Freire's Theory of Problem-Posing Education. Then, I explain how both contribute to fostering critical thinking skills and dispositions and critical awareness in the science educational environment.

In the fourth chapter, I analyze the theory and practice of socioscientific issues and explain the contributions of a socioscientific issue approach to enhancing students' understanding of the nature of science and students' argumentation, reflective, and decision making skills.

In the fifth chapter, I discuss the implications and recommendations for incorporating the theoretical components of the three theories mentioned above in middle school science education and end with my conclusion.

Summary

In chapter one, I presented the rationale, my personal experience and interest in the research topic, the problem statement, the purpose, and the assumptions behind writing this thesis. The literature related to science education involves a broad scope of diverse philosophical and theoretical orientations that aim to promote curricular content and pedagogical change. In my thesis, I focus on analyzing three theories: the Theory of Learning and Experience of John Dewey, the Theory of Problem-Posing Education of Paulo Freire, and the theory and practice of socioscientific issues to examine their contributions to making science more meaningful and relevant to students' lives.

Figure 1

Fallacies Characterizing the Dominant Cultural Norms of Science Education

Fallacies in School Science Education	Fallacies Translated into the Science Educational Practice
1- the foundational fallacy	The foundational fallacy originates from a pedagogy of science that focuses on delivering diverse bits of scientific knowledge for students to understand the whole concept without focusing on the value and relevance of the concept in the students' living reality.
2- the fallacy of coverage	The fallacy of coverage relates to the imposition of a broad science curriculum which promotes cramming and shifts the focus on the quantity of knowledge rather than the quality of the science learning experience.
3- the fallacy of a detached science	The fallacy of a detached science presents science as idealistic, objective, and value free.
4- the fallacy of critical thinking	The fallacy that science education promotes critical thinking is based on the assumption that learning science fosters a sense of critical rationality.
5- the fallacy of the scientific method	The fallacy that there is one scientific method is based on the assumption that a singular scientific method exists which means scientists follow a single logical procedure.
6- the fallacy of utility	The fallacy of utility is based on the assumption that scientific knowledge is important to the mastery of technology and recognition of its influences and to live at ease in the culture of technology dominating one's social life.
7- the homogeneous fallacy	The homogeneous fallacy reflects the teaching of science as a one-size fits all curriculum regardless to the students' diverse aptitudes, abilities, and social realities.

Chapter Two- Visions Conceptualizing the Meaning of Scientific Literacy

Introduction

In Chapter Two, I present the different visions of scientific literacy. I suggest that shifting science education towards a more relevant and responsive approach demands embracing a holistic vision of scientific literacy that, in addition to learning scientific concepts and applying scientific practices, promotes the development of a responsible and critically aware citizen. Accordingly, learners are empowered to make meaning of science and use scientific knowledge to engage effectively in decision-making processes regarding science and technology-related social issues and take actions that promote positive changes to the world.

Science education is often linked to citizenship, whereby many countries and governments have created policy statements that consider the sciences an essential factor for developing an informed and engaged citizenship (Roth & Désautels, 2004, p. 3). Within policy statements related to science curricula, citizenship has been argued in terms of 'scientific literacy' (DeHart Hurd, 1998). Achieving scientific literacy is a common objective of science education in schools (Bybee, 1997). According to Miller and Osborne (1998), the primary and explicit goal of the 5-16 science curriculum entails providing a course which can improve students' 'scientific literacy', as this is fundamental for all youth whether choosing to be future scientists or to follow any other career.

Bybee (1997) suggested that scientific literacy in schools can be considered at four functional levels that are:

1- the nominal level (can recognize scientific terms but does not have a clear understanding of the meaning);

2- the functional level (can use scientific and technological vocabulary, but usually this is only out of context as is the case for example in a school test or examination);

3- the structural -conceptual and procedural- (demonstrates understanding concepts and the relationship between concepts and can use processes with meaning);

4- The multidimensional level (not only has understanding but has developed perspectives of science and technology that include the nature of science, the role of science and technology in personal life and society).

The multidimensional level is recognized as the feature that gives scientific literacy a long term view in the area of science literature (Bybee, 1997). It directs its goals towards the students' ability to make decisions on technological applications of scientific ideas and socioscientific issues rather than merely acquiring a conceptual understanding of scientific laws, theories, and ideas (Bybee, 1997). Within this context, scientific literacy helps students develop skills and mobilize and construct knowledge that guides their decisions and actions.

Different Visions of Scientific Literacy

There are many definitions and conceptualizations of scientific literacy in the science education literature, and there is little agreement about the meaning of scientific literacy in terms of curriculum provision (Hodson, 2003; Sadler, 2011).

Vision I

Roberts (2007a) created an empirical framework that provides a synthesis of the different ideologies on scientific literacy. He identified two competing visions; Vision I and Vision II. Vision I is scientist-centered aiming to enculturate learners into scientific disciplines (Aikenhead, 2007, p. 1). It focuses on literacy “within science” (p. 730) and gives meaning to scientific literacy "by looking inward at the canon of orthodox natural science, that is, the products and processes of science itself" (Roberts, 2007a, p. 730). Here, school sciences largely reflect a status quo-oriented and a traditional science pedagogical framework (Roberts, 2007a) which is the main reason for the students' low interest and enrollment in school science (Aikenhead, 2007, p. 1). Historically, the ideology of Vision I reflects Eurocentric politics of privilege and elitism (Aikenhead, 2007).

Vision II

Vision II is learner-centered and context-driven, aiming to enculturate learners into their local, national, and global communities (Aikenhead, 2007, p. 1). It focuses on literacy about science-related issues in which considerations other than scientific knowledge and facts are included in the process of science teaching and learning. These situations with a scientific component are likely to encounter students as citizens (Roberts, 2007a, p. 730). Within Vision II, science is perceived as a human endeavor that strengthens students' abilities to participate in decision-making processes. The choice between Vision I and Vision II in the science education practice varies from one that promotes decreased student engagement and decreased scientific literacy to one that increases scientific literacy and makes school science more relevant to students' social reality (Aikenhead, 2007). Like Vision I, Vision II reflects Western/Eurocentric perspectives on science (Aikenhead, 2007).

Zeidler (2007) explains how teaching and learning of science through a socioscientific issues framework can contribute to a more inclusive and comprehensive position of Vision II. He argues that moral reasoning, ethical considerations, and character development are essential elements to understanding scientific literacy. Otherwise, its conceptualization and significance fail to meet the goals of science education concerning the development of actively engaged and informed citizens. Accordingly, he advocates for a socioscientific issue epistemological approach that promotes students' conceptual understanding of scientific and social matters in order to actively engage in decision-making regarding controversial issues with moral or ethical implications.

Vision III- Pluralistic Science and Functional Scientific Literacy

Aikenhead (2007) explained that scientific literacy within the ideology of Vision I and Vision II is restricted to literacy in Eurocentric science. It supports the agenda that positions science as a subculture of the Euro-American culture (Aikenhead, 2000) and ignores pluralism in science which includes; Eurocentric science, Indigenous sciences and neo-Indigenous science as identified by Aikenhead and Ogawa (2007). For Aikenhead (2007), a mono-cultural science pedagogical approach causes a cultural clash between the culture of science education in the school and the home culture of the students, which leads to student alienation and learning disengagement. Accordingly, he advocated for addressing educational and political goals in conceptualizing scientific literacy.

In a study by Bang et al. (2013), the authors argued for "de-settling" existing expectations of standardized science curricula and pedagogies, highlighting how deficit driven discourses locate students from non-dominant cultures in "untenable epistemological positions" that inhibit meaningful engagement in learning science (p. 302). The questions and contributions of minority learners that do not align with the Western science curriculum were dismissed in classroom discussions related to properties that characterize the living and non-living. The narrow framing of science definitions and knowledge leads to the reinforcement of systemic inequities (Bang et al., 2013; Robertson & Atkins Elliot, 2017). Moreover, it prevents opportunities that give space for sharing diverse perspectives on the same phenomenon, which can deepen students' learning about a particular science concept or definition (Bang et al., 2013; Ojalehto et al., 2015). It is noteworthy to point here that the intention of pluralizing science is not to devalue Eurocentric science. However, it is a direction towards a more empowering, culturally relevant, and inclusive vision of scientific literacy. It shows how Eurocentric science functions in students' local, national, and global cultures and how Indigenous and neo-Indigenous sciences are related to local and cultural ways of knowing and understanding (Aikenhead, 2007). Simultaneously, it fosters a more transformative science education culture that respects students' heterogeneous sense-making and generates expanded forms of knowledge and engagement beyond the norms of standardized curricula (Bang et al., 2013, pp. 314-315).

Yore (2012) proposes Vision III of scientific literacy that mainly focuses on the literacy dimension in science to equip future citizens with the literacy and skills that empower them to make informed decisions and actions. Literacy plays a functional role in constructing the students' abilities to understand and articulate scientific discourse and convey knowledge claims (Yore, 2012). Learning science requires students to read texts, analyze figures, design investigations, and compose scientific arguments in the science classroom. Due to high-stakes testing requirements, students spend more time acquiring the technical aspects of reading and writing skills instead of generating new understandings within science (Cervetti et al., 2009). This perpetuates oppressive conditions in schools that oppose how individuals can use literacy and science to better understand their relationship with the world around them (Hoffman, 2017).

Yore's Vision III of scientific literacy is based on a socio-cognitive framework that integrates the nature of science and the language of science and emphasizes the social dimension of science. The nature of science refers to ontological and epistemological beliefs (p. 9). Whereas, the language of science refers to the fundamental "constructive, persuasive, and communicative functions of languages in doing science" (p. 7) which include language in scientific discourse (oral and written) and language in teaching and learning of science. There are two interacting goals within Vision III which are developing a "fundamental sense of being literate in science" and developing "knowledge of science and the scientific enterprise" (p. 7). These goals integrate the cognitive, affective, and technological abilities related to science to promote understanding of human endeavors in nature and their relation to naturally occurring events. Additionally, they generate a reciprocal relation between scientific knowledge and society which fosters more individual engagement "in science" through participation in scientific debates and "with science" through confrontation or dialogue (p. 5).

Vision III- Critical Scientific Literacy

Sjostrom and Eilks (2018) vision III is a more critical view underpinning scientific literacy, which falls within a radical direction to science education aiming for socio-echo justice and socio-political action. Sjostrom and Eilks (2018) argue for a politicized and praxis-oriented scientific literacy that is justified by the Central/Northern European education tradition known as *Bildung*. Bildung is a contested, complex, and multifaceted educational and philosophical concept (Gustavsson, 2014; Sjostrom & Eilks, 2018) that mainly consists of two elements that are: the free process of personal development to form the self of a human being and the ideal image which means the goal or the results of this development process (Gustavsson, 2014, p. 111). It is a German term used in the International educational literature because it hasn't any specific translation in English (Gustavsson, 2014; Sjostrom & Eilks, 2018). According to Gustavsson (2014), the central "aim and meaning of bildung is to humanize what is often considered to be an instrumental education and society , governed by goal-rationality and goal-mean efficiency" (p. 109). He explained three versions of bildung that are Classical Bildung, Anglo-American Bildung and Bildung as a journey (Gustavsson, 2014) or Critical-Reflexive Bildung as proposed by (Sjostrom & Eilks, 2018). Additionally, Burman (2011) identified two civic-oriented bildung traditions that are the Scandinavian folk-bildung and Dewey's democratic education as cited by Sjostrom and Eilks (2018). I do not intend to explain the meanings of the five bildung traditions, but I will focus on the Critical-Reflexive Bildung that supports the argument for socio-political action and praxis-oriented Vision III (Sjostrom & Eilks, 2018) for scientific literacy.

A Critical-Reflexive Bildung has political and educational dimensions (Biesta, 2012a) that pave the way to different perspectives in the theory and practice of science and scientific literacy. It is positioned as a critical concept in modern pedagogy that incorporates

1. aims related to socialization, education, and instruction not included in other modern pedagogical theories (Wimmer, 2003);
2. aims directed towards consciousness, critical literacy, socio-eco justice, transformation, and dialogical emancipation (Sjostrom & Eilks, 2018); and
3. aims advocating for sociopolitical participation (Elmos & Roth, 2005).

A Critical-Reflexive Bildung in science education aligns with education for sustainability, transformative learning, and transformative science education (Sjostrom & Eilks, 2018, p. 67) and emphasizes "transdisciplinarity, philosophical values and praxis-oriented global citizenship" (p. 77). Its practical implications empower students to achieve self-determination in their socio-cultural context, establish informed participation within a democratic society and build solidarity with others (Elmos & Roth, 2005).

To apply Critical-Reflexive Bildung in the educational context, a tool known as "Didaktical Analysis" was developed by Klakfi (2000) and others as being a part of the Critical

Constructive Didaktic (as cited in Sjostrom & Eilks, 2018, p. 70). This tool includes questions that reflect the extent of relevance of a topic to be taught and the meaning students make of learning about this topic (Klakfi, 2000). These questions tend to identify knowledge and issues to learn about, which are important for the individuals and the society that students live in and operate today and in the future (Sjostrom & Eilks, 2018, p. 70). As a result, students learn about how global and local issues are handled within society and understand the interactions between science and politics, economics, culture, beliefs and the natural environment.

Sjöström and Eilks (2018) vision of scientific literacy resonates with Hodson's (2003) argument for politicizing science education to foster critical scientific literacy. According to Hodson (2003), politicizing science education is essential to promote a critical scientific, technological, and environmental literacy that enables citizens to take "appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern" (p. 658). Critical scientific literacy relates to goals of critical citizenship which involve critical thinking and critical pedagogy and aim for citizens that are autonomous, critical, and ethically aware when making decisions and taking actions (Johnson & Morris, 2010). According to Hodson (2003), politicizing science education demands allowing students "to confront real world issues and grounding content in socially and personally relevant contexts that have a scientific, technological or environmental dimension" (p. 645). He emphasized that a major element of scientific literacy is the capacity of individuals to engage critically and actively with text (p. 646) to develop a degree of political literacy to transform knowledge into political action and go beyond the role of "armchair critic" (p. 645). He positioned science as "culturally dependent and culturally transforming," which means that science cannot be taught as static and fixed knowledge, but it is rather “a product of its time and place” that changes quite radically the ways in which people think and act (p. 12).

To reinforce his argument, Hodson (2003) suggested a socio-scientific issues-based approach to trigger “the motivation that is absent from current abstract, de-contextualized approaches and form a base for students to construct an understanding that is personally relevant, meaningful, and important (p. 654). The issue-based approach proposed by Hodson (2003, p. 12) incorporates four levels of sophistication:

Level 1: Appreciating the societal impact of scientific and technological change and recognizing that science and technology are, to some extent, culturally determined.

Level 2: Recognizing that decisions about scientific and technological development are taken in pursuit of particular interest, and that benefits accruing to some may be at the expense of others. Recognizing that scientific and technological development are inextricably linked with the distribution of wealth and power.

Level 3: Developing one’s own views and establishing one’s own underlying value positions.

Level 4: Preparing for and taking action.

Developing scientific literacy within the context of Critical-Reflexive Bildung and Hodson (2003) issue-based approach demands the activation of a relevant science education framework that develops students' critical thinking to develop awareness towards one’s own way of learning and one’s perspectives and to establish “both a relationship and a critical stance towards the existing culture and society” (Biesta, 2012a, p. 817). Most important, it reflects a conception of a human identity that can maintain a responsible interaction with other individuals and the natural world.

Summary

This chapter presented the different visions of scientific literacy and their implications in science education. It was explicit how moving from Vision I to Vision III transformed the view of science from a narrow scientist-centered discipline towards a more transformative, interdisciplinary, and politicized science educational framework. Vision, I focused on teaching disciplinary content within a positivistic learning environment. Vision II focused on contextualizing science by teaching relevant science content to help students understand the usefulness of science in daily life and develop the ability to make informed decisions about socio-scientific issues. Vision III reflects an inclusive and holistic view of science including its position, language, and function. It focuses on creating a science educational environment that engages students in relevant, culturally responsive, transformative, and politicized science education to strengthen values and social responsibility.

Within Vision III, Aikenhead (2007) emphasized pluralism in science, Yore (2012) advocated for participation in and with science through focusing on the literacy component of scientific literacy, and Sjostrom and Eilks (2018) proposed a Critical-Reflexive Bildung/politicized/praxis-oriented Vision III. I strongly advocate for Vision III of scientific literacy to instill students with the necessary knowledge, attitudes, and skills that empower them to make informed and responsible decisions and actions that bring more justice and sustainability to our world. Chapters Four and Five will demonstrate how theoretical contributions of the Theory of Learning and Experience of John Dewey, the Theory of Problem-Posing Education of Paulo Freire, and the theory and practice of socioscientific issues help orient science education towards the goals of Vision III of scientific literacy.

Chapter Three- Theory of Experience and Learning and Theory of Problem-posing Pedagogy

Introduction

In Chapter Three, I analyze John Dewey's Theory of Experience and Learning and Paulo Freire's Theory of Problem-Posing Pedagogy. Then I explain how both theories can contribute to fostering an active, relevant, and critical approach to school science teaching and learning. Accordingly, students can develop the necessary knowledge, critical thinking skills and attitudes, and social responsibility to actively participate with their local and global community. Students need to perceive science as part of their social reality and engage in science-related decision making-processes responsibly and critically to transform their reality. The philosophical and pedagogical perspectives underlying the theoretical works of John Dewey and Paulo Freire advocate for a relevant, meaningful and empowering science education that aims for individual growth and social change.

John Dewey's Theory of Experience and Learning

John Dewey was an American philosopher, psychologist, progressive educator, and social reformer whose educational theory was based on his philosophy of experience rooted in his philosophy of democratic education (Dewey, 1938, p. 29). To Dewey (1916), the purpose of education is to promote the intellectual, moral, and emotional growth of an individual and consequently to nurture a democratic society that ensures the participation and freedom of all its members. He believed that an educational system needs to furnish the learning environment with the tools that help learners develop habits of mind and a personal interest in social relationships to be prepared to function responsibly in their community to improve society. Dewey's vision of teaching and education is explicitly demonstrated in one of his most known articles, "My

Pedagogical Creed" (1897). According to Mooney (2000), Dewey's Pedagogical Creed identifies five critical educational perspectives related to students' learning:

1- the need for the curriculum to be centered on students' interests,
2- the need for the curriculum to address real-world problems relevant to students' needs,
3- the need for cooperative work between students and their peers and teachers
4- the need for teachers to be responsive to students' cultural backgrounds and values
5- the need for teachers to act as facilitators that guide and direct their students towards growth not only to achieve educational outcomes but also to learn how to live

Dewey's work influences nearly all aspects of science education, what science education should achieve, and how science should be perceived (Wong & Pugh, 2014, p. 1). His philosophical view about science entails transforming the way science is taught in schools as "ready-made knowledge" separated from the students' experiences and social environment (Dewey, 1910). He emphasized that science is an active process, practice, or method of thinking (1910) with the central aim of science education to equip students with the thinking habits that enable them to inquire for the best interests of humans (Dewey, 1948, p. 206). Accordingly, Dewey (1948) involved values in the scientific practice stressing that science is not value-free as viewed with the positivist perspective. However, it is value-laden because value is a feature of all science practical actions and decisions.

Moreover, Dewey (1948) argued that science education should be inquiry-oriented to develop students' reflective/critical thinking and moral and social skills that promote knowledge construction and active engagement in society. He emphasized learning by doing, stating that "there is no such thing as genuine knowledge and fruitful understanding except as the offspring of doing" (p. 284), with knowledge being an outcome of individuals' active participation in the process of inquiry (Dewey, 1916). In today's classrooms, science pedagogical approaches that include Inquiry-based learning, project/problem-based learning, and culturally relevant pedagogy align with Dewey's progressivist goals to engage students in contextualized and meaningful science learning experiences (Wong & Pugh, 2014, p. 1).

Theory of Experience

Dewey (1956) pointed to the gap existing between the students' everyday experiences and the isolated school material. He explained that for the child

> a great waste in school comes from his inability to utilize the experiences he gets outside the school in any complete and free way within the school itself; while on the other hand, he is unable to apply in daily life what he is learning in school (pp. 75-76).

Dewey believed that education and experience are strongly connected. He was against traditional educational approaches that perceive the child as "the immature being who is to be matured" through passive listening and reception of fixed knowledge (Dewey, 1902, p. 13). Instead, Dewey placed the students' experience, interests, and needs at the center of instruction to stimulate and promote learning.

Dewey defined education as "the reconstruction and reorganization of experience, which adds to the meaning of experience and which increases ability to direct the course of subsequent experience" (1916, pp. 89-90). In his book, *Experience and Education*, Dewey (1938) explained that "all genuine education comes about through experience" (p. 25). However, not all experiences are truly and equally educative (p. 25), with the main challenge of "an education based on experience is the "continuity of experience" or the "experiential continuum" (p. 28). Dewey classified experiences as educative and mis-educative even when they constitute the basis of learning. He stressed that it is the quality of an experience that determines meaningful learning and empowers students to consciously perceive and value the events occurring in their lives in order to act with responsiveness and purpose. The quality of an experience relates to its “immediate aspect of agreeableness or disagreeableness” and “influence upon later experiences” (p. 27).

Mis-educative Experience

According to Dewey (1938), a mis-educative experience is one which impedes learning. It arrests or distorts the growth of further experience, resulting in callousness and lack of sensitivity (p. 25). It can also lead an individual into “routine action” which would increase a learner’s mechanical skill to perform a specific task. Consequently, it does not widen one’s perceptions and connections with the changing world causing action without an awareness of how this action influences others and the environment, which “limits rather than widens the meaning-horizon” (Dewey 1916; p. 91). To Dewey, mis-educative experiences are present in the traditional education settings that treat students as passive receptacles of knowledge and reduce their ability to experience a sense of agency (Jenlink & Jenlink, 2019) and engage in real-life applications. Accordingly, science education that positions science as a discipline of truth and adopts a decontextualized pedagogical framework is mis-educative, because it fails to respond to students’ needs and interests in a world greatly influenced by science and technology.

Additionally, it narrows the space for their curiosity to develop further questioning and reflection on what they learn. Many of the teaching and learning activities implemented in the classroom may be enjoyable and exciting for students in practice, but they do not provoke intrinsic motivation to learn and make meaning of science as part of one’s daily life. For example, in middle school science, students learn to analyze, interpret and justify their answers. However, the teacher's focus is developing the student's ability to apply thinking skills and use adequate science language to answer assessment questions. Instead, the primary educational aim should be building students' skills to learn how data analysis, interpretation, and argumentation can help them understand the nature of science and question and validate information in newspapers, articles, or social media regarding socioscientific issues. This dichotomy between teaching/learning of a skill/content as a means to passing assessment and teaching/learning of a skill/content to promote an informed participation in decision-making processes and actions reflects the gap between science taught in schools and science required in real life/public. It also explains Dewey's notion of mis-educative experience.

Educative Experience

Dewey (1938) explains that an educative experience leads into new perceptions and broadens an individual's consciousness about the connections of earlier and later experiences. It is active, goal-directed, change-oriented, and connected to the individual and the world. Two necessary principles determine the quality of an educative experience: the principle of interaction and continuity. The principle of interaction suggests that students make meaning of their experience as they engage and interact with their social and physical environment, which includes "whatever conditions interact[ing] with personal needs, desires, purposes, and capacities to create the experience which is had" (p. 44). Accordingly, direct engagement in an activity does not imply that learning occurs. Instead, the interactions that occur with oneself, the teacher, the classmates, the curriculum, and the external environment constitute an experience. At the same time, they reveal the extent and the influence of learning from experience. The principle of continuity is wholly linked to interaction, and it is central to Dewey's concept of learning and teaching, explained as subsequent experience. On the individual level, the principle of continuity proposes that learners make sense of a new experience by linking it to previous experience in addition to the knowledge they know about the world. This prior knowledge acts as “an instrument of understanding and dealing effectively with the situations which follow” (p. 44). On the societal level, the principle of continuity focuses on social growth or continuity through the “renewing of the social group” (p. 39). For Dewey (1916), growth depends on the need to interact with others and on “plasticity,” which is the power to learn from experience and form active habits as thought, invention, and initiatives that promote the application of capacities to new aims (p. 62). Teachers may increase the likelihood that their students will engage in educative experiences by investing enough time “to utilize the surroundings, physical and social, to extract from them all that they have to contribute” to learning (Dewey, 1938, p. 40).

Reflective Thinking

According to Dewey, an experience alone, even an educative one, is not enough to generate thought because an experience itself is not primarily cognitive (Rogers, 2002, p. 848). Educative learning experiences accompany reflection/reflective thinking/critical thinking so that learners investigate and perceive “the relationships or continuities” to which an experience leads up (Dewey, 1916 p. 140) and hence make meaning of the experience. This meaning-making process or reflective thought is at the core of what it means to be a human being (Dewey, 1916). In his argument for reflective thinking, Dewey (1933) described it as “an active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it and the further conclusion to which it tends” (p. 9).

Reflective thinking is based on a careful inquiry process that underlies knowledge assumptions. It includes the recognition of an actual problematic situation and a state of uncertainty about the solution to this situation which are two mandatory factors to get engaged in an authentic inquiry. Reflective thinking or inquiry ends with a reflective judgment. According to Dewey (1916), the judgment formulated during the inquiry process must be based on evidence and valid reasoning about sources of information that do not rest on authority, emotions, or opinions and thus exist outside of the involuntary or predetermined thoughts of the thinker. Moreover, a reflective judgment would not always lead to a solution for the recognized problem, but it would lead towards truth or the best possible answer, which is open to further criticism, investigation, and subsequent inquiry. Therefore reflective thinking is not an end itself. Instead, it is a vehicle for individuals to make sense of and give value to experiences, apply what they learn, and direct subsequent experiences in their life to achieve moral ends (Dewey, 1938, p. 49).

Rogers (2002) presented four criteria that characterize the concept and purposes of reflection in Dewey's writings in How We Think, Democracy and Education, and Education and Experience. The first criterion relates to Dewey's theory of experience in which reflection is "a meaning-making process that moves a learner from one experience into the next with a deeper understanding of its relationships with and connections to other experiences and ideas" (Rogers, 2002, p. 845). The second criterion relates to Dewey's philosophy of thought in which reflection is a "systemic, rigorous disciplined way of thinking, with its roots in scientific inquiry" (Rogers, 2002, p. 845). Within this criterion, Dewey distinguishes reflective thinking from three kinds of thought: stream of consciousness, invention, and belief.

1- Reflective thinking differs from 'stream of consciousness in that the latter presents an individual's thinking in an involuntary state whereby an uncontrolled flow of thought runs through one's head daily. In contrast, reflection is voluntary and comprises interlinked thoughts to move the individual towards a common end (p. 849).

2- Reflective thinking differs from ‘invention’ in that invention involves imagination and mental ideas that might not be directly observed or existing in reality. Reflective thinking draws on past experience, involves facts and is completely grounded in one’s reality. Nevertheless, this does not mean that imagination and reflection are not related, as Dewey still sees imagination important within reflective thinking (p. 850).

3- Reflective thinking differs from 'believing' in that believing includes instances, ideas, and thoughts that an individual accepts with limited observation or arrested inquiry as prejudices and prejudgements (p. 850). Beliefs generated through genuine reflective thinking can are considered as knowledge, but this knowledge is also susceptible to future questioning as new facts or circumstances appear (Dewey, 1933).

The third criterion that characterizes Dewey’s concept of reflection relates to reflection in community and the need to interact with others. Dewey (1938) envisions education as a social function and school as a social community that empowers students to learn through cooperation, dialogue, reflection, and action. Reflective thinking in isolation is not sufficient if there is no communication and participation with the community to share experiences and broaden the meaning horizon of our own experience. According to Dewey, “One has to assimilate, imaginatively, something of another’s experience in order to tell him intelligently of one’s own experience” (1916, p. 6). He asserts that coping with our changing world is a collective responsibility that requires human beings to establish proper social relationships that allow intelligent participation and reasonable response to challenges. Collaborative reflection affirms the value of one’s own experience, widens the field of understanding an experience enabling the individual to see diverse meanings, supports an individual to engage in the process of inquiry, and develops a sense of responsibility towards others (Rogers, 2002).

The fourth criterion that characterizes Dewey's concept of reflection relates reflection to a set of attitudes that value the personal and the intellectual growth of oneself and others (Rogers, 2002, p. 859). Dewey was aware of the affective dimension of learning, and he believed that "there is no integration of character and mind unless there is a fusion of the intellectual and the emotional, of meaning and value, of fact and imaginative running beyond fact into the realm of possibilities" (1933, p. 278). He believed that an individual's attitudes or dispositions could either promote or inhibit learning through reflective inquiry. Whole-heartedness, directness, open-mindedness, responsibility, and readiness to engage in reflective inquiry are all attitudes that increase one's learning through reflective inquiry (Dewey, 1933).

Reflective Inquiry and Decision-Making Skills

Dewey's perspective about inquiry in science education plays a prominent role in explaining how inquiry can teach students value judgment and consequently develop their ability to make informed decisions related to socio-scientific and controversial issues in society. Dewey (1948) explained that inquiry and values are related because the way inquiry is guided is influenced by values. Interests that are external, irrelevant and "alien to conduct of knowing as its own and proper terminus" misguide inquiry (Dewey, 1948, p. 206) and consequently prevent the contributions of science to nurture social, moral, and democratic ideals in society. However, inquiry that is carried based on critical thinking, supportive evidence and evaluation would lead to decisions that are as intellectual as possible. Accordingly, scientific inquiry should involve critical thinking and a practical judgment guiding each action with the corresponding results reflecting the values of each practical judgment (Dewey, 1948). According to Lee and Brown (2018), Dewey's perspective about scientific inquiry provides a connection for the 'missing link' about how conducting scientific inquiry can promote informed decision-making in science-related issues. They proposed that through the practical/reflective judgment that is a value judgment directing students' actions during inquiry, students develop the critical thinking skills that guide them towards informed decision-making. They suggest that students should (pp. 14-15)

1- know that different values are involved in scientific inquiry in the science classroom
2- know that they are making a practical/reflective value judgment during each step in the scientific inquiry, and they can evaluate the involved values through the results of the inquiry
3- know that conducting a scientific inquiry requires good value judgment.

Dewey's philosophy of experience and reflective thinking encourages us as educators to reconsider our perceptions about science and our subjectively held perspectives about science teaching to reconstruct and transform our science pedagogical practice. It fosters a humanistic vision of science presenting it as "closely attuned to human problems" and "continuous with, rather than dichotomous from, other human activities" (Waddington & Weeth, 2016). Planning educative science experiences that engage students in reflective/critical inquiry develops students' critical thinking to act as action-oriented and responsible future citizens who can make positive contributions to the local and global community.

Paulo Freire's Theory of Problem-Posing Education

Paulo Freire was a Brazilian educator, philosopher, and social theorist, and he is one of the most influential leaders of critical pedagogy, which is rooted in critical theory. Critical theory mainly focuses on unbalanced power relations, which constitute a key means for analyzing and critiquing inequality and injustice in academic opportunities, social institutions, and power structures (Darder, Baltodano & Torres, 2003). Freire's radical educational theory reflects a humanistic philosophy that aims for humanization and authentic liberation through the act of ‘conscientization’ which means the awakening of one’s critical consciousness to become fully human (p. 36). Freire (2000) explained that education either acts as a “practice of domination” (p. 81) to promote conformity or acts as “the practice of freedom” to empower learners to think and act critically and creatively to make changes to their reality (p. 34). He articulated that our objective social reality exists not by chance, but it is the product of human action.

As a result, a historical task for humans, as conscious beings and “beings of praxis” (Freire, 2000, p. 100), is to use knowledge to deepen our critical awareness of the world around us and challenge the dehumanizing acts of oppression, violence, exploitation, and injustice. Freire’s writings focused on popular education and social justice issues and racial and economic inequality, and they influenced fields such as philosophy, pedagogy, social science, and literature (Santos, 2009). He is also known for the adult literacy program that he developed while working with peasant communities which had great results in reducing the illiteracy rates in different parts of the world in Latin America and South Africa.

For Freire (1973, 2000), education cannot be a neutral process. However, it encompasses a political agenda whereby essential questions that relate to the type of politics that education serves and for the favour of whom or against it is realized must always be raised. He argued that a market-driven educational system is dehumanizing because it limits the learners’ freedom to express their perspectives relative to their interactions with the world to act upon it and transform it (Santos, 2009, p. 364). Accordingly, he pointed that teachers who act apolitically, unintentionally, or naively during the teaching and learning process perpetuate hegemonic ideologies imposed by technological systems (Santos, 2009, p. 376). In the context of science education, this means that embracing Vision I to scientific literacy and teaching school science as a depoliticised subject divorced from the existential social reality of students is oppressive. It emphasizes the benefits of scientific and technological advancements without critically discussing their influence on society and the natural environment (Santos, 2009). Additionally, it ignores human inconstancy and ideology and the political and social context that frames scientific knowledge (Parsons, 2019). As a result, students passively accept the "domination of technological values over humanistic values" without having the opportunity and space to critically reflect on the oppression existing in the modern scientific and technological society as well (Santos, 2009, p. 373).

Transforming this learning context demands that both teachers and students act as critical co-investigators of controversial social and environmental science and technology-related issues. Accordingly, they can use scientific information to develop a conceptual understanding of an issue and engage in arguments, dialogue, and debates that promote critical thinking to recognize how an issue relates to political, cultural, social, and economic factors. Involving Freirean perspectives in the science pedagogical framework integrates political reflections within the aims and goals of critical scientific literacy to prepare future citizens for sociopolitical action through the lens of critical pedagogy (Santos, 2009). Freirean perspectives reflect a radical view of science education. They provide a transformative stance that promotes contextual and reflective learning experiences making science education more responsive, humanistic, and aligned with goals of responsible citizenship.

In his most famous book, *Pedagogy of the Oppressed*, Freire (2000) explained the contradiction between the oppressors and the oppressed; how the oppressors dehumanize the oppressed through acts of domestication and manipulation hidden under slogans of liberation, and how the oppressed themselves while naively and unquestionably adopting their oppressors' agenda of liberation maintain the oppression of their communities. He emphasized that resolving the oppressor-oppressed contradiction and attaining “authentic liberation – the process of humanization” cannot occur through a mechanistic, naturalistic and spatialized view of consciousness. Instead, consciousness is constructed from reality by confronting reality critically through “praxis”, that is the “action and reflection of men and women upon their world in order to transform it” (p. 79). To Freire (2000), praxis is the raison d’être of the oppressed, and achieving praxis requires solidarity and mutual trust between individuals to create a space for critical dialogue, reflection, and transformative action.

Banking Model of Education

Freire (2000) criticized traditional educational methods, and he argued that educators should reject the ‘banking’ model of education, which positions the teacher as the knowledgeable subject and the students as receptacles receiving “deposits entrusted to them” (p. 77). He described the ‘banking’ model of education as dehumanizing, passive, and irrelevant to students’ lives because it creates a dichotomy between the students and their reality and consequently maintains a culture of oppression. In the ‘banking’ model of education, students are treated as individuals “merely in the world, not with the world or with others”, and there is limited space for authentic thinking, critical reflection, and creativity (p. 75). As a result, learners act as spectators who adapt to a fragmented view of reality rather than re-creators who are critically aware of their reality to intervene in transforming their world (p. 75). Osborne and Hennessy (2007) argued that the banking model in school science narrows students’ space to develop critical thinking that is essential in science education and a key skill for democratic citizenship. It also limits their opportunities to engage in reasoning and arguments about socioscientific issues that contribute to social and environmental injustice.

Problem-Posing Education

Freire (2000) proposed a “problem-posing” educational approach rooted in critical pedagogy and based on a dialogical theory of praxis and a partnership between teachers and students that simultaneously places both as teachers and learners. Problem posing education is active, emancipatory, and responsive to students’ living reality. It positions science learning as part of a broader struggle for justice and democracy to promote social transformation (Giroux, 2010). Since reality is “a process of constant transformation” (Freire, 2000, p. 75), the construction of knowledge occurs only through ‘hopeful inquiry human beings pursue in the world, with the world, and with each other (p. 72). As students are increasingly posed with problems relevant to their lives, their questions become more critical, and they become more challenged to seek answers that they need to respond to upcoming challenges. Hence, they are empowered to “develop a consciousness of freedom, recognize authoritarian tendencies, connect knowledge to power and agency, and to challenge ideological and material forces that shape their consciousness” (Giroux, 2010, p. 336).

Problem-posing education has communication at its centre. Through dialogue and continuous reflection and action, it aims to promote solidarity and authentic thinking that is meaning-thinking concerned about reality and action upon the world. Accordingly, students act as subjects rather than objects in the process of learning and knowledge construction (p. 83). They perceive their learning experience as "something they do, not something done to them” (Shor, 1993, p. 26). Within this context, the role of classroom teachers is to act as thought-provoking and empowering agents that encourage students’ curiosity and activism about knowledge and the world” to engage in social change and democracy (Shor, 1993, p. 26). For Freire (1998), an anti-dialogic authoritative education opposes the nature of human beings, their ability to discover and create. It also inhibits democracy that is only taught and learned through an authentic practice of democracy.

In Freire's liberatory pedagogy, every individual has the right to have a voice and be an active part of the teaching-learning process through dialogue which constitutes a fundamental principle for education for critical consciousness. According to Freire (2000), emancipatory dialogue is an "existential necessity" that humanizes men and women to interact with reality and create and recreate to achieve human significance and human liberation (Freire, 2000, p.89). It is a technique of "illumination" (Shor & Freire, 1987, p. 13) that becomes a "part of our historical progress in becoming human being" (Shor & Freire, 1987, p. 13). Communication among participants is accompanied by critical reflection regarding what we know and what we do not know to think and act critically.

Emancipatory Dialogue

Emancipatory dialogue rejects teaching as a method of narration of scientific concepts and facts. It differs from authoritative teacher-students communication strategies and student-student discussions that mainly focus on acquiring conceptual knowledge and achieving student participation or learning assessment grades. Emancipatory dialogue promotes students' deeper thinking and contributes to development of critical awareness, character and values. It engages students in critical reflection and critical thinking about assumptions and predetermined knowledge. Through dialogue, the role of an educator deviates from one who dispenses knowledge and imposes views of the world on students to one who engages with students in the process of questioning, investigating, discovering, deconstructing, and reconstructing knowledge. The educator has a sociopolitical stance and acts as a co-learner and co-researcher with students to help them recreate knowledge and learn in a new way (Shor & Freire, 1987, p.

11) to generate informed perspectives. The openness of the dialogic educator to the process of re-learning with students rather than authoritarian possession of knowledge gives dialogue a democratic character.

Freire's dialogical approach in problem-posing education promotes responsive, relevant and transformative learning through critical inquiry that is shaped by science concepts and teacher preparation. Establishing authentic dialogue with students demands that educators nurture a learning environment infused with love, humility, hope and critical thinking (Freire, 2000).

- Love is a fundamental factor to allow a dialogical relationship between educators and learners. It includes love for the world and for the people to liberate oneself and others rather than to dominate or alienate others.
- Humility is another factor to establish a relationship based on mutual trust and partnership between students and teachers and to have faith that every individual can learn, create, and transform. According to Freire, a dialogical relationship changes to a 'paternalistic manipulation' without faith in others (p. 91).
- Hope is necessary to nurture a dialogic relationship that is driven by motivation and expectations. Dialogue cannot happen in a 'climate of hopelessness' (p. 92). Learning in an environment shaped by passivity and silence maintains a culture of obedience that suppresses human curiosity and creativity.
- Critical thinking is another factor required for dialogue and generated by dialogue. In Freire's explanation, critical thinking is thinking that breaks the dichotomy between the world and the people to promote solidarity between them. It recognizes reality as "a process, as transformation, rather than as a static entity—thinking which does not

separate itself from action, but constantly immerses itself in temporality without fear of the risks involved" (p. 93). Critical thinking in science education will be discussed further in this chapter.

To implement problem-posing pedagogy in the science classroom, educators must be change-oriented and committed to activating a critical inquiry approach with their students to foster social and environmental justice. Accordingly, they need to question and reflect on their beliefs about science and the science educational practice and their relation with the learners and community. Educators need to make science in schools meaningful and be aware that science has historicity (Shor & Freire, 1987). This means that "all new knowledge comes up, when other knowledge becomes old and no longer answer the needs of the new moment, no longer answers the new questions being asked" (Shor & Freire, 1987, p. 16).

Freirean Perspectives in Science Education

In an approach to integrate humanistic Freirean perspectives in science education, Santos (2009) explains that teaching science through a Freirean lens activates a radical view of scientific literacy. It demands the educator to introduce students to relevant socioscientific issues through a dialogic approach to engage them in debates about their cultural context and at the same time to generate a thoughtful and active study of scientific concepts. He suggests that a Freirean perspective in science education can be achieved through three phases that are:

1- observation of the students' reality to identify social issues and engage students in discussions of socially relevant themes by socioscientific issues to help students generate reflections on the social context of oppression in the modern scientific and technological society

2- discussion of the learners' existential situation by engaging students in debates arising about the chosen issues through a dialogical process in the classroom to explore the values embedded in these discussions and to teach scientific concepts

3- discussion of actions to transform that reality and promote students' engagement in sociopolitical action (pp. 373-374)

Incorporating Freirean perspectives in science education is greatly significant to direct its goals towards strengthening human values over technological and market values. For example, teachers engage students in discussions of how science and technological advancements driven by the economic system increase power and wealth inequality and environmental degradation. Consequently, students can examine diverse perspectives and reflect on the role of political, financial, social, and cultural factors when interpreting, judging, and making-decisions about science related problems.

The issue-based approach proposed by Hodson (2003, 2010) aligns with Freire's problem-posing pedagogy. Hodson emphasized the importance of designing learning experiences that help students understand how products of science and technology are "culturally dependent and culturally transforming" and how they influence the social, cultural and economic fabric of society, including the way individuals think, act and talk (2010, p. 200). He advocated for promoting students' critical awareness of environmental racism while learning about problems that cause environmental degradation. Within this context, students can realize how the poor, disadvantaged, and marginalized are mostly impacted by environmental degradation, while rich and powerful groups achieve economic and political benefits (Hodson, 2010). An example that echoes this issue is the tragic story of my hometown Bar-Elias that suffers catastrophic consequences on its people's health and environment due to the Litani River pollution. About six hundred cancer cases were recorded in Bar-Elias in 2019 and the people now call it the river of death. This oppressive reality demands that teachers use the case of Litani River pollution as a theme for students to learn scientific concepts and investigate the sociopolitical factors causing this social and environmental damage to engage in transformative action. Students need to recognize that solving a socioscientific problem as the Litani River pollution needs a scientific solution and a sociopolitical action.

A Freirean pedagogy is important to promote an activist and transformative science education because it focuses on the political nature of education. It demands that teachers have self-awareness of their beliefs and be committed to social change. It also stresses the necessity for teachers to be ethical and not to impose values on students to help them discover different choices available (Freire, 1994) and develop skills, dispositions, and values necessary for responsible action. Hence, integrating Freire's pedagogy in the science teaching and learning practice encourages future citizens to utilize scientific and technological advancements to reduce inequality and inequity and maintain environmental sustainability. Nevertheless, many constraints related to teacher identity, teacher professional development, standardized curricula and assessment, and institutional policies complicate the implementation of a critical pedagogy in the science educational practice.

Implications of Deweyan and Freirean Perspectives in Science Education

For Dewey (1916) and Freire (1970), education acts "as a democratizing force and a catalyst for individual development and social transformation" (Reis, 2014, p. 549). Dewey's theory of experience/reflective inquiry and Freire's theory of problem-posing education/dialogical pedagogy places the student's experience at the center of the curriculum and instructional approach. Both emphasize the need for a learning culture that is relevant to students' realities to respond to their needs and interests. Additionally, both advocate for learning through critical inquiry to instill students with the necessary knowledge, attitudes, and critical thinking skills that expand their perception of ideas to see and think in alternative and new ways that guide them towards informed decisions and actions within a democratic society.

Dewey’s focus in critical inquiry promotes the learner's intellectual, moral, and ethical development through engagement in reflective thinking. His perspective relates to increasing awareness of the potential of one’s own experience through 'learning by doing' to participate actively in society and bring about change. However, Freire’s focus in critical inquiry is the development of the learner's critical consciousness of societal oppression and injustice to transform society through critical action. Freire's perspectives emphasize leaners' engagement in authentic dialogue and sociopolitical action to deconstruct and reconstruct reality and achieve 'praxis' and 'human liberation'. Hence, incorporating Freirean and Deweyan perspectives in science education aligns with the goals of Vision III of scientific literacy or critical scientific literacy.

Freirean and Deweyan perspectives have a great influence on the pedagogical practice and the teaching/learning environment. The teacher needs to be reflective, committed to social change and acting as a learning facilitator and co-investigator that raises questions and seeks answers with students to solve problems rather than being an authoritative dispenser of knowledge. The pedagogical approach needs to be responsive, relevant and contextualized. It involves ethical, socio-political and socio-cultural perspectives in the teaching and learning of science to help students understand uncertainties, values and politics in science, scientific research and technological advancements. Therefore, students can decide critically where to stand and how to act regarding socio-scientific issues and other technology related issues that bring risks and challenges in our world. The curriculum should include themes that address problems relevant to students' lives so that students can raise personally meaningful questions that instigate curiosity, motivation and a sense of responsibility.

Critical Thinking in Science Education

John Dewey and Paulo Freire emphasize the importance of critical thinking to promote informed decision-making and individual/social transformation. Critical thinking is a 'multifaceted concept' with different meanings in diverse contexts (Vieira et al., 2011, p. 46). From a psychological perspective, Ennis (1985) defines critical thinking as "a form of rational, reflective thinking, focused on deciding what to believe or do" (p. 46). It involves cognitive abilities and dispositions that enable students to think and act critically (Ennis, 1985). A critical thinker is disposed to justify decisions and make judgments by being focused, well-informed, open-minded, and caring (Ennis, 1996). These attitudes demand the ability to question and clarify, seek and judge well the basis for a view, consider and evaluate alternative points of view, and respect others' beliefs and feelings (Ennis, 1996). Similarly, Halpern (2006) associated critical thinking with argumentation, problem-solving, and decision-making abilities. In any teaching context that aims to promote critical thinking, learners can develop critical thinking dispositions and abilities to the extent that time and learner capabilities permit (Ennis, 1996).

Philosophical contributions to critical thinking relate to instilling a skeptical disposition regarding the homogenous dominant discourses that limit one's opportunity to recognize how diverse social, political, and cultural factors interplay within society (Habermas, 1971). Its primary focus is to question predetermined perspectives and structure counter-arguments to have a responsible and transformative role in decision-making processes. Within this context, critical pedagogy associates critical thinking with the pursuit of individual and collective liberation (Freire, 1970).

Critical thinking plays a central role in the science educational practice. It is key to developing students' scientific literacy and informed engagement in arguments, discussions and debates. Critical thinking competences increase students' understanding of the nature of science as a human activity integrated with technological, societal, and environmental aspects (Lederman, 1992). Yacoubian (2015) explains that critical thinking in science education favors a more informed view about nature of science and deepens students' conceptual knowledge to foster informed decision-making regarding socioscientific issues. He developed a Critical Thinking-Nature of Science (CT-NOS) framework that aimed to promote students' critical thinking "about" nature of science and "with" nature of science as they engage in socioscientific issue decision making (p. 258). The interlinkage between critical thinking and informed decision-making emphasizes the importance of critical thinking to nurture students' moral and ethical values and a sense of responsibility towards society and the environment (Yacoubian, 2015). Therefore, critical thinking plays a significant role in fostering democracy in society because it promotes informed participation in decision-making processes related to the uses and applications of scientific and technological advancements.

Osborne (2014) argues for fostering a science pedagogical framework that challenges students' thinking by inviting critical questions and critical thinking (p. 55). He finds that the absence of critical thinking has negative consequences on students' learning which include overemphasis on lower-level cognitive skills; less effective processes of learning; failure to communicate or represent the nature of the discipline; and less engaging experiences for students (p. 54). Accordingly, he asserts the role of critical thinking and critical questioning in science education to trigger epistemic curiosity and empower students to defend their position cognitively. This deepens thinking and engages students in a “dialogue between construction and critique” to understand and evaluate ideas and construct knowledge (p. 55).

To develop students’ critical thinking and critical questioning skills, Osborne (2014) suggests that teachers need to

1- model question asking , ask students to pose questions in the classroom, a reflective journal, homework, and collaborative group work, and include a question asking as an evaluation strategy (p. 60)
2- engage students in critique, argumentation, reflective discussions and questioning not only to help build students’ understanding of science but also to develop their ability to reason scientifically (p. 53)
3- encourage students to evaluate the ideas in a critically, reflective and rational manner by encouraging critical questioning of existing knowledge and perspectives to critically compare the evidence with the predictions and arguments and with what students observe
4- explore, identify and respond to students’ preconceptions and misconceptions about scientific issues (p. 56)
5- develop students’ ability to undertake the cognitive process of complex reasoning, which includes critical thinking, non-routine problem solving, and constructing and evaluating evidence-based arguments. (p. 59)
6- create a safe, inclusive, and respectful learning environment that invites students to express their ideas, to question critically, to share their real-life experiences, and to think reflectively.

Many challenges obstruct the development of students' critical thinking skills and dispositions in science classrooms. They include the lack of a consistent conception of critical thinking in science education curricula (Bailin, 2002), the instrumental view of science education that focuses on content memorization, and the lack of teacher training to teach and implement strategies that promote students' engagement in critical questioning, reflective discussions and evidence –based arguments which contribute to promoting critical thinking (Osborne, 2014). For the latter, it is recommended that teachers engage in professional training to learn how to think reflectively and how to teach critical thinking and implement reflective thinking activities in the science classroom (Santos, 2017).

Summary

In chapter three, I analyzed John Dewey's theory of experience and learning and Paulo Freire's theory of problem-posing pedagogy to illuminate how the philosophical and practical perspectives underlying these theories contribute to transforming the view and practice of science education in schools. Both reflect the importance of shifting school science from "pipeline science" which aims to prepare future scientists to science as a social enterprise (Aikenhead, 2006) to foster a relevant and responsive science educational practice that enhances students' scientific literacy and understanding of the nature of science. Moreover, both prioritize the necessity of developing students' critical thinking skills and attitudes in science classrooms to help them act as active and responsible citizens and participate responsibly in decision-making processes regarding science-related social and environmental dilemmas.

Chapter 4- Theory and Practice of Socioscientific Issues

Introduction

In Chapter Four, I present the theory and practice of socioscientific issues and explain the contributions of integrating socioscientific issues as a context for teaching and learning in science education in schools. First, I clarify the meaning of socioscientific issues. Then I highlight the contributions, challenges, and recommendations for implementing a successful socioscientific issue instructional framework that can serve as a vehicle to promote students' critical thinking and social activism (Zeidler, 2014). I end this chapter by elaborating how the COVID-19 pandemic, as a socioscientific issue and global dilemma, provides a relevant science learning context that harnesses students' cognitive abilities, values, and emotions to transform their view of science and better understand the relation between science and their reality. Accordingly, they can develop the necessary knowledge and skills to participate responsibly in decision-making processes and social action.

The Meaning and Practice of Socioscientific Issues

Socioscientific issues are local and global controversial issues that "describe societal dilemmas with conceptual, procedural or technological associations with science" (Sadler, 2004b, p. 342). The meaning of the term 'controversial issue' in the context of science education is explained by Dearden (1981) as a matter in which "contrary views can be held on it without those views being contrary to reason" (p. 38). In explaining "reason," Dearden (1981) clarifies that "reason" here does not mean "something timeless and unhistorical, but the body of knowledge, criteria of truth, critical standards, and verification procedures which at any given time have been so far developed" (p. 38). As issues of controversial nature, they are ill-structured

(Zeidler & Sadler, 2007). They can be considered from multiple perspectives without having simple conclusions (Sadler, 2004b, p. 342) and tend to have multiple plausible solutions informed by scientific principles, theories, and data (Sadler, 2011, p. 4). In addition to scientific considerations, these solutions involve various social, cultural, political, economic, moral, and ethical factors (Sadler, 2011) that reveal diverse and conflicting views present within our society. Ratcliffe and Grace (2003, pp. 2-3) summarize the properties of socioscientific issues as follows. Socioscientific issues

1. have a basis in science, and frequently are at the frontiers of scientific knowledge;
2. involve forming opinions, making choices at personal or societal level;
3. are frequently media-reported, with attendant issues of presentation based on the purposes of the communicator;
4. deal with incomplete information because of conflicting/incomplete; scientific evidence, and inevitably incomplete reporting;
5. address local, national and global dimensions with attendant political and societal frameworks;
6. involve some cost-benefit analysis in which risk interacts with values;
7. involve values and ethical reasoning;
8. may require some understanding of probability and risk; and
9. are frequently topical with a transient life.

Examples of socioscientific issues that create a learning context in the science classroom include global warming, environmental problems, genetically modified organisms and products, human cloning, antibiotics, mass extinction, oil spills, nuclear power, and the contemporary COVID-19 pandemic.

According to Zeidler (2014), a socioscientific issue framework in science classrooms aligns with progressive goals in education that aim for social responsibility and social competence. Its associated pedagogy engages students in reflective inquiry to interpret issues, make decisions including moral judgments, solve problems and engage critically in different forms of discourse as argumentation and negotiation that are in the long term aimed at the development of virtue and character (Zeidler, 2014, p. 698). It is also focused on developing students' sense of open-mindedness, which is a necessary habit of mind to consider, generate and evaluate new and different forms of knowledge (Zeidler, 2014).

In the context of socioscientific issues, intentional actions are considered rational to the extent they are responsive to reason. Dealing with socioscientific issues involves a degree of moral reasoning or the evaluation of ethical concerns in decision-making regarding the possible resolution of these issues (Zeidler & Sadler, 2007; Zeidler & Nichols, 2009; Yap, 2014; Zeidler, 2014). It is the value underlying the moral action rather than the principle in itself that provides the ultimate ground for its justification (Zeidler, 2014). Accordingly, reasoning concerned with socioscientific issues reflects values that frame our lives as individuals living in and with the social, natural, and physical world around us. Integrating values in science education through socioscientific issues embraces a sociocultural perspective for developing scientific literacy (Zeidler, 2014). Hence, it humanizes science education, making science more relevant and responsive to the social context in which students learn.

Socioscientific Issues and Science Technology Society

A socioscientific issue (SSI) framework and a Science-Technology-Society (STS) framework are related in that both connect science to societal issues (Chowdhury, 2016). However, the problem-solving approach within STS lacks connections with other factors related to science as the ethical, moral, values, character education, emotional, personal, and understanding of the nature of science (Chowdhury, 2016, p. 26). A socioscientific issue framework focuses on the social reality of learners to develop content knowledge, functional scientific literacy, and qualities of virtue and character (Pedretti & Nazir, 2011; Zeidler, 2014). It targets the affective and cognitive aspects of learning (Chowdhury, 2016). Additionally, it addresses philosophical and empirical questions (Chowdhury, 2016) to interlink science with various factors that make classroom explorations more effective and relevant for students to understand scientific concepts and recognize the ethical, moral, financial, and political factors related to an issue (Kolstø, 2001). As a result, dealing with socioscientific issues focuses on the students' psychological and epistemological growth (Pedretti & Nazir, 2011) and provides a context for the public understanding of science (Zeidler et al., 2013, p. 278).

Contributions of Integrating a Socioscientific Issue Instructional Approach in Science Classrooms

The reviewed literature about socioscientific issues reveals that implementing a socioscientific issue instructional framework in science classrooms promotes students' development of scientific literacy, critical thinking, and responsible citizenship. It increases conceptual knowledge acquisition, understanding of the nature of science, and the relevance of science by utilizing personally relevant controversial problems that employ the use of scientific topics (Sadler et al., 2007; Sadler, 2011; Zeidler, 2014). Moreover, it serves as a context for students' active engagement in dialogue, discussions, debates, informal reasoning, and evidence-based argumentation (Sadler et al., 2007; Zeidler, 2014) to achieve educational and citizenship goals that prioritize critical thinking. These goals encourage students to ask questions, validate claims and counterclaims, and research to recognize the importance of reliable data and evidence that form an essential component in resolving socioscientific issues (Sadler, 2004a).

Accordingly, students can connect science with their social reality and reflect on how science and technology relate to and impact society to participate in informed decision-making processes which prioritize responsible citizenship goals. (Kolstø, 2001; Sadler et al., 2007; Zeidler & Nichols, 2009; Zeidler, 2014).

Socioscientific Issues and Responsible Citizenship

The inclusion of socioscientific issues in the science curricula can have a prominent role in fostering responsible citizenship through the activation of a functional view of scientific literacy that involves "evidence-based reasoning accompanied by ethics and values of care, responsibility and compassion about the quality of the world that we live in" (Evagrou & Dillon, 2020, p. vi). Moreover, advocates of critical scientific literacy (Vision III), as Hodson (2003), Santos (2009), and Sjöström and Eilks (2018), envision a politicized science education that involves a socioscientific issue framework to promote responsible citizenship and social activism.

Socioscientific issues can bridge the gap between school science and students' lived experiences to prepare students for active participation in society and promote democratic citizenship through science education (Kolstø, 2001, Sadler et al., 2007). Driver et al. (2000) stress that youth must receive an education that enables them to "both construct and analyze arguments relating to the social application and implications of science" (p. 297). Similarly, Harlen (2006, 2010) argues that science education should empower each individual to understand and assess the impact and the benefits and risks of science and technology in daily life and be open to alternative perspectives based on scientific evidence. Accordingly, students can have an informed part in decision-making processes that relate to the well-being of oneself, society, and the environment. Students should learn science through educative experiences

(Dewey, 1938) which illuminate the social dimension of science, the limitations of science, ethics and values in science and critical action.

The contributions of socioscientific issues to promoting citizenship were analyzed in Chowdhury et al. (2020) literature review that examined how socioscientific issues within science can foster the development of the “desired citizenry” (p. 203). The "desired citizenry" in the study context refers to Westheimer and Kahne (2004) and Kahne and Westheimer (2006) perceptions of kinds of citizens that include: personally responsible, participatory, justice-oriented, and politically concerned citizens. In their analysis, Chowdhury et al. (2020) found that a socioscientific issue framework empowers students to connect science to local, national, and global issues faced by scientists and other citizens in their lives. It involves political and community-based work that builds students' sense of responsibility, sense of community, self-expression and self-actualization. It also provides space to view and make reflective judgments to assess the risks and benefits of solutions and recognize how values, ethics, and moral reasoning influence decisions regarding science-related dilemmas. However, multiple challenges related to the controversial nature of socioscientific issues and instructional design obstruct the successful implementation of a socioscientific issue instructional framework and act as barriers to promoting the desired citizenry. I will discuss challenges in this chapter.

Aspects of Socioscientific Reasoning and Critical Thinking

In a study by Sadler et al. (2007), a socioscientific reasoning theoretical construct was designed to assess the aspects of socioscientific reasoning of middle school students in a Midwestern United States Town. Students explored pollution, specifically the water quality dilemma, through a 3D virtual, multiuser environment known as Quest Atlantis. The virtual experience aimed to help students recognize and understand how multiple factors as water chemistry, aquatic biology, human-nature interactions, management, economics, and politics contributed to the water quality dilemma (p. 378). For Sadler et al. (2007), four important aspects of socioscientific reasoning are most effective for decision-making concerned with socioscientific issues. These aspects are:

1- Recognising the inherent complexity of socioscientific issues; Sadler et al. (2007) emphasize that students negotiating socioscientific issues need to recognize the dynamic interactions within the problem rather than attempting to make decisions based on a simple cause and effect reasoning (p. 375). Accordingly, teachers should avoid focusing on a single feature of an issue because this excludes its broader contextual significance, which makes it relevant to students' reality.

2- Examining issues from multiple perspectives; Sadler et al. (2007) explain that reasoning on socioscientific matters does not necessarily privilege a single perspective but "it should not be assumed that all perspectives are equally defensible" (p. 376). Students and teachers need to consider alternative views and seek evidence to evaluate arguments and counterarguments to establish informed decision-making.

3- Appreciating that socioscientific issues are subject to ongoing inquiry; the degree of uncertainty involved within the scientific and social dimensions of socioscientific issues provides several possibilities for open-ended inquiry (p. 376).

4- Exhibiting skepticism towards potentially biased information; students need to demonstrate skepticism in the face of biased information and strategies, which means that they need to carefully assess the credibility, reliability, and selection of the

> information sources as these are essential to make informed decisions regarding the selection of references (p. 376).

The findings of Sadler et al. (2007) study revealed that students' correlations with complexity and inquiry aspects were relatively high, but those with perspectives and skepticism were relatively low. Given that both aspects, being open to multiple perspectives and being aware of the credibility of information sources, demand critical thinking skills. The study makes explicit two crucial implications. First, there is a lack of critical thinking skills and integrating socioscientific reasoning in the science pedagogical practice can serve as a vehicle to promote students' critical thinking skills and dispositions. This resonates with Solbes et al. (2018) who also emphasize that dealing with socioscientific issues in the science classroom facilitates the development of students' critical competencies. The second implication sheds light on the influence of the learning context and the situatedness of knowledge on shaping students' socioscientific reasoning aspects.

Socioscientific Reasoning, Culture and Beliefs

Social and cultural factors influence students' perspectives and reasoning patterns in discussions and debates regarding controversial issues. Zeidler et al. (2013) embraced a cross-cultural perspective to investigate the epistemological reasoning patterns of culturally diverse high school students (i.e., Grades 10, 11, 12) from different countries, including USA, Jamaica, Sweden, Taiwan, and South Africa. Students' epistemological reasoning on the issue of distributive justice was examined to show how students organize, evaluate and utilize scientific evidence (p. 256).

According to Zeidler et al. (2013), epistemological reasoning includes epistemological orientations and epistemological sophistication. Epistemological orientation "indicates the various perspectives that an individual may hold about an issue," which means the way one makes meaning of an issue relative to one's relation with the world" (p. 252). Epistemological sophistication "refers to either the developmental level and/or quality of the reasoning itself", which means the way an individual articulates arguments to justify decisions about an issue (p. 252). The findings of the study revealed that all students had commonalities in ethical considerations about the concerned socioscientific issue, but only Taiwanese students demonstrated higher levels of epistemological sophistication and consequently approached decision-making more holistically. Zeidler et al. (2013) emphasize that culture influences the epistemic practices of socially constructed knowledge. It sheds light on how students' epistemological beliefs and values influence their conceptualization of ethical considerations within socioscientific issues and consequently "contextualize the ability to formulate scientifically based questions to inform their decisions" (p. 279).

In a study by Yap (2014), ethical frameworks were used as a pedagogical tool to explore the influence of moral and ethical factors on decisions regarding socioscientific issues. Connecting socioscientific issues with morality and ethics position socioscientific issues as moral issues because they involve "objective, prescriptive and generalizable standards" (Yap, 2014, p. 300). The study engaged Grade Ten students aged 14 to 15 in socioscientific reasoning about ethical issues and/or moral problems within genetic engineering and assessed how cognitive abilities, values, and beliefs facilitated students' critical thinking, argumentation and decision making. The findings of the study revealed that the incorporation of faith values in the ethical frameworks indicated that other concepts besides that of justice and fairness could affect one's judgment on what is morally right. Belief systems and ideologies can sometimes predominate in making decisions of moral rightness, which demands the need to consider these factors when designing curricula for socioscientific education (p. 315).

Challenges to Implementing an Effective Socioscientific issues Teaching and Learning Framework in School Science

Socioscientific issues involve uncertainty, controversy, values and moral and ethical considerations which make a traditional authoritative content-centered approach ineffective to implement an effective socioscientific issue framework. There are different challenges that obstruct the successful implementation of a socioscientific issue teaching and learning framework in science education in schools leading to a dichotomy between theory and practice or a gap between expectations and results of integrating socioscientific issues in science curricula (Kilinc et al., 2017). These challenges relate to teachers' beliefs and teaching practice, science curricula, and institutional policy. It is emphasized that science teachers play an important role in influencing the students' educational experience and hence in promoting students' learning and engagement (Santos, 2009; Zeidler, 2014).

According to Zeidler (2014), teachers' pedagogical beliefs and identity (Zeidler, 2014) can positively or negatively influence teaching and learning through socioscientific issues. A socioscientific issue framework demands structural shifts in teachers' normative beliefs about the goals of education as well as epistemic shifts in the science pedagogical practice. (Zeidler, 2014, p. 703). However, the ability of teachers to transform their beliefs and practice requires "a multitude of challenging contextual factors residing in students, administration and oneself" (p. 704). While some teachers find it necessary to infuse ethics and values in science education, others are hesitant due to personal, pedagogical, and institutional constraints (Zeidler, 2014). Studies show that teachers' reluctance to teach controversial issues relate to the marginalized position of socioscientific issues in science curricula (Pedretti et al, 2008), the lack of required instructional materials and time due to test-centered curricula (Zeidler, 2014; Kilinc et al., 2017), lack of epistemological and pedagogical knowledge related to teaching socioscientific issues (Reis, 2014; Kilinc et al., 2017) and lack of stakeholders support to teachers (Kilinc et al., 2017).

Britt et al. (2011) examined teachers' and students' (aged 13 to 16) experiences in working with socioscientific issues from a multidimensional perspective that considered student motivation, cognition, and attitudes. They emphasized that the teaching and learning approach which is mostly handled by the teachers and the strategies for engaging students in organized discussions and arguments are necessary elements to foster an effective socioscientific issue framework. Additionally, the autonomy of students and the relevance of the issue are essential for students' interest in socioscientific issues. One of the findings in the study demonstrated that teachers maintained the view of socioscientific issues as special and focused on teaching scientific content as a primary objective which implies the need for epistemic and pedagogical shift in practice.

Recommendations for Fostering an Effective Teaching and Learning Socioscientific Issue Framework

Recommendations for Teachers

Presley et al. (2013, p. 29) recommend that implementing a socioscientific issue-based instruction in science classrooms require teachers to have specific attributes which include:

a) familiarity with the socioscientific issue considered; teachers need to understand the scientific conceptual knowledge related to the issue and be aware of the potential political, ethical, and social considerations associated with an issue to help students make informed decisions.

b) teachers as learners; teachers should be aware of knowledge limitations and be willing to transform their role from authoritative knowledge dispensers to knowledge contributors, facilitators, and co-learners with their students.

c) willingness to deal with uncertainties in the classroom given the open-ended feature relative to socioscientific issues; teachers need to transform the traditional science discourse and practice. Engaging and empowering learning experiences that encourage students to share what they know, reflect on what they learn, consider alternative perspectives, and craft coherent arguments must be activated.

Additionally, Presley et al. (2013, p. 30) recommend that teachers receive adequate support from the school, the community, and state and national policies which includes:

1. Access to SSI-based materials.
2. Flexible curriculum that allows teachers to integrate socioscientific issue instruction.
3. Existence and awareness of local community issues to activate socioscientific issue instruction.
4. Strategies for negotiating community concerns or disapproval of socioscientific issue instruction.
5. Connections between socioscientific issue curricula and state or national curriculum objectives.

Recommendations for Teaching and Learning Environment

Presley et al. (2013) explain that effective socioscientific instruction requires a safe and supportive learning environment that sets high expectations for student participation, engages students in collaborative and interactive experiences, and maintains a respectful relationship between students and teachers (p. 30).

Recommendations for Teaching Practice

Scaffolding is an important strategy for facilitating student engagement and argumentation concerned with socioscientific issues. Teachers need to scaffold scientific concepts to address different positions within media, government, and commercial and diverse perspectives regarding a socioscientific issue (Zeidler, 2014). Additionally, they need to provide proper scaffolding for higher-order thinking practices and design structured activities that support students' analysis of multiple perspectives and promote sophisticated forms of argumentation (Presley et al., 2013). The studies reviewed by Sadler (2004a) show that students make naive arguments to support their claims regarding a socioscientific issue. They do not attend to counter-positions and rebuttals because of the lack of argumentative and epistemic operations. Argumentative operations refer to the structure of an argument, but epistemic operations refer to conceptual knowledge related to the addressed socioscientific issue (Sadler, 2004a).

Moreover, using different forms of media and technology tools is necessary to provide students with access to relevant local and global issues and greater diversity of sources (Presley et al., 2013), which can enhance students' research skills and media literacy when accompanied by teacher guidance. However, it is noteworthy to highlight the massive spread of misinformation, disinformation and conspiracy theories in media sources which demands being critical and aware of the credibility of sources and trustworthiness of data. Sadler (2004a) study shows that students have naive views about the meaning of data. There is a need to help students learn evaluation strategies and develop skills to evaluate the reliability of news, reports, and articles about socioscientific issues.

Students need to engage in reflective thinking experiences to critically assess the usefulness of information (Sadler, 2004a, p. 522). Sadler (2014) recommends engaging students in inquiry-based socioscientific issue learning through web-based technology as the WISE platform (Web-Based Inquiry Science Environment). The WISE platform encourages students to use more evidence-based content and craft reflective arguments. The COVID-19 pandemic is already a socioscientific topic integrated into the WISE platform for grade eight students.

The COVID-19 Pandemic- A Relevant Context for Socioscientific Reasoning

The COVID-19 pandemic provides an effective opportunity to transform our view about the role of science and scientific and technological advancements in our daily lives. It forms a relevant context for understanding the nature of science, learning diverse scientific concepts, articulating evidence-based arguments, and evaluating information and data resources. It can also promote student engagement in reflective moments that illuminate how political, financial, socio-cultural, and ethical factors interlink with science.

The COVID-19 pandemic serves as a context to design themes that engage students in learning scientific concepts aligned with multiple curricular objectives. Examples are topics related to the human body systems, mainly the immune system anatomy and physiology that is already present in grades 8 and 9 curricula and topics related to virology and epidemiology, which study COVID-19 structure, function, and pathology; COVID-19 variants and COVID-19 transmission and prevention. Through these themes, students can analyze reports, articles, and graphs on different media sources to construct evidence-based arguments regarding various claims, beliefs, and measures.

Additionally, the COVID-19 pandemic provides a context for social and political engagement. It encourages students to ask critical questions about issues of inequity and oppression in terms of access to good health care, issues related to the effectiveness of vaccines and booster shots, issues related to mandated, controlled, or uncontrolled application of safety measures and issues related to the privatized scientific research. According to the World Health Organization (2020), the Coronavirus is the first pandemic in history that is associated with an overabundance of information on media, both online and offline, thus forming an *infodemic* that challenges global response. An infodemic involves endeavors that spread fallacious information to serve alternative agendas of groups or individuals (World Health Organization, 2020). Misinformation and disinformation can negatively influence the public's physical and mental health (World Health Organization, 2020). Additionally, disinformation politicizes public debates and discussions regarding COVID-19, which amplifies hate speech and threatens human rights, democracy, and social cohesion (World Health Organization, 2020).

The multidimensional impact of the COVID-19 pandemic on every aspect of our lives and the massive amount of information spread on the media stress the need to prioritize and activate a significant goal of science education: critical thinking. Within this sense, critical thinking involves cognitive skills and dispositions (Ennis, 1985) and engagement in authentic emancipatory dialogue (Freire, 1970) to foster critical scientific literacy (Vision III) that is essential to raise socially responsible future citizens. According to Dillon and Avraamidou (2020), the pandemic makes explicit the "inseparability" of science and social justice and it emphasizes the importance of critical thinking to "re-think the complex systems and socio-political contexts within which people come to learn and practice science and to conceptualize these processes through a social justice lens" (p. 6). Implementing a socioscientific issue framework that engages students in critical inquiry regarding controversies and challenges embedded in the COVID-19 pandemic is a gateway to activate a multidimensional learning approach that entwines the cognitive with the social and emotional aspects of learning to help students construct knowledge, develop critical awareness, and build a socially responsible character.

Summary

In Chapter Four, I analyzed important aspects of the theory and practice of socioscientific issues. I also highlighted the contributions of a socioscientific issue instruction to science education, the challenges in practice mainly for teachers, and the recommendations for implementation. It is evident in the literature that a properly designed socioscientific issue instructional framework serves as a relevant context for conceptual and epistemological development and for fostering students' reflective and critical thinking. Socioscientific issues illuminate the social dimension of science, the limitations in science, ethics, and values in science, and serve as a means to promote critical action.

Chapter 5- Summary, Recommendations, Challenges, Implications

Introduction

In Chapter Five, I reiterate the problem in science education and the contributions of the three examined theoretical frameworks: Dewey's Theory of Experience and Learning; Freire's Theory of Problem-Posing Education, and theory and practice of socioscientific issues. I argue that the philosophical, epistemological, and pedagogical perspectives underlying these theories can transform science education in middle school classrooms to establish a relevant and responsive science educational context that strengthens the vision of critical scientific literacy and promotes students' intellectual and character development. I also discuss the implications of this research and recommendations for science educators and science teaching practice.

School science is still presented for students within a positivist culture that presents scientific knowledge as depoliticized and decontextualized and narrows students' space to make meaning of their learning experience and how science relates and influences their own lives as citizens in a democracy. Additionally, science teaching is more teacher-directed and content-centered with a great focus on content memorization and high stakes testing requirements. There is little or no space for students to reflect on their learning, engage in science-related discussions and debates, learn how to articulate evidence-based arguments, and practice the sophisticated argumentation that is a necessary skill for informed decision-making. In spite of implementing problem-based learning and inquiry learning in science classrooms, the over-sized curricula and overemphasis on the quantity of knowledge rather than the quality of the knowledge limits opportunities that equip students with the necessary skills, attitudes, and critical awareness to deconstruct oppressive structures and transform their reality. The culture of passivity in learning also maintains the gap between science learned in schools and science presented to the public, making science learning irrelevant to many students. Consequently, “educative experiences” that can develop students’ critical thinking as a habit of living to engage responsibly in decisions and actions are lacking in science classrooms. Within this context, Vision I of scientific literacy dominates regardless of the reforms advocating for Vision II and Vision III of scientific literacy.

However, the strong connection of science with the personal, social, political, cultural, ethical, moral, and economic dimensions in our social reality, locally and globally, demands future citizens who are critical thinkers to act as critical consumers of knowledge in a world manifested by risks and uncertainties. Science education should empower students to critically examine science-related social and environmental issues and dilemmas and act towards the pursuit of strengthening human values, human dignity, and social and environmental justice. Accordingly, it is essential to shift science education in schools toward a framework that advocates for Vision III of scientific literacy to create a relevant, politicized and transformative science education context that prioritizes critical thinking and incorporates values and responsible citizenship in learning.

Implications

The philosophical and practical perspectives underlying the Theory of Learning and Experience of John Dewey, the Theory of Problem-Posing Education of Paulo Freire, and the theory and practice of socioscientific issues offer significant contributions and implications to science education. The three theories oppose traditional approaches to science education that focus on memorization of concepts and facts and application of teacher centered activities. They foster a humanistic science educational culture that places students' experiences and needs at the center of learning to promote the meaningfulness and relevance of science. The three theories emphasize that science is value-laden and encourage educators to reconsider their perceptions about science and their subjectively held perspectives about science teaching to reconstruct and transform the science pedagogical practice and teaching/learning context. Additionally, the three theories contribute to enhancing students' open-mindedness, argumentation skills, and social interaction which are necessary to promote students' critical thinking and responsible citizenship and students' informed engagement in decision-making processes.

Dewey's Theory of Learning and Experience emphasizes the need to equip students with the thinking habits that enable them to inquire for the best interests of humans. He believed that science education should be relevant and open to discussions related to contemporary events rather than being disconnected from the students' reality. This is necessary for students to develop habits that make them "more intelligent, more sensitively percipient, more informed with foresight, more aware of what they are about, more flexibly responsive than those current" (Dewey, 2002, p. 128). The science educational experiences should strengthen individual interaction with the social reality through communication, reflection, and action. Students need to develop reflective thinking to learn how to think and make meaning of scientific knowledge and judge or decide with awareness to the consequences of their decisions. Accordingly, they can recognize that values and social responsibility are important factors in the process of decision making. Whole-heartedness, directness, open-mindedness, responsibility, and readiness are all necessary attitudes to allow students' active participation in reflective inquiry (Dewey, 1933).

Freire's Problem-Posing Pedagogy emphasizes the importance of politicizing and contextualizing school science education through student engagement in discussions of socially relevant themes within socioscientific issues (Santos, 2009). It is centered on the notion of 'praxis' that is a continuous cycle of reflection and action to develop students' critical awareness of societal oppression and injustice caused by modern scientific and technological advancements and power structures. Authentic dialogue and critical inquiry that value students' sociocultural knowledge and position students and teachers as subjects and co-learners/co-investigators in the learning process characterize science education through Freirean perspectives.

The theory and practice of socioscientific issues serve as a vehicle for activating science learning experiences that promote epistemological sophistication. Socioscientific issue reasoning involves values, ethical and moral considerations, and evidence-based argumentation. It triggers students to ask and investigate personally relevant questions and engage in discussions, debates, and data analysis and interpretation to consider, generate, and evaluate new and different forms of knowledge (Zeidler, 2014). An appropriate design and implementation of socioscientific issue instruction can help students develop aspects of socioscientific reasoning which promote students' capabilities to: a) recognize the inherent complexity and dynamic interactions within socioscientific issues, b) to consider diverse perspectives and evaluate personal arguments and counter-arguments, c) to appreciate that socioscientific reasoning involves open-ended inquiry, and d) to demonstrate skepticism and carefully assess the credibility of information sources and reliability of evidence. These aspects enhance students' understanding of the nature of science, improve conceptual understanding and increase students' critical analytical skills when using media to inquire about socioscientific problems. Accordingly, students can become more aware of the need to have a critical, open-minded, and socially responsible attitude to establish informed participation in public debates and decision-making processes.

Recommendations

Pre-service and in-service education programs must engage teachers in activities that enhance reflective and critical thinking to form an informed view of the meaning of critical thinking in practice and consequently learn how to design and apply science instructional approaches that help their students develop critical thinking. Argumentation, case analysis, graph analysis and interpretation, deep discussions and critical inquiry concerned with socioscientific issues can provide a context for learning to teach critical thinking. Encouraging teachers to pose critical questions, examine multiple perspectives, validate claims and counter-claims and evaluate their decisions or judgments are all strategies that teachers can learn and apply in their classrooms. Additionally, engaging teachers in socioscientific issue reasoning enables them to integrate multidisciplinary views with science and encourages them to critically reflect on their science teaching identity and epistemological and pedagogical beliefs. Consequently, they can recognize how the teaching and learning context influences students' conceptual understanding, views about the nature of science and the role of science in their lives and their role as responsible citizens in the local and global community.

Science teachers need to act as reflective practitioners and facilitators of learning. Lesson planning and science instruction should be accompanied by the teacher's self-awareness of the positionality of oneself in terms of teaching style and assumptions and critical reflection to evaluate the relevance and responsiveness of the science educational experiences to students' social reality and how these experiences can promote responsible citizenship skills. Rather than focusing merely on textbook content, middle school teachers should engage in professional learning communities and build collegial and collaborative relationships to design relevant instructional material and learning experiences that transcend classroom boundaries. Accordingly, they can incorporate values and sociocultural perspectives in science through the involvement of social issues and environmental problems existing in the students' community.

Science teachers need to act as facilitators of meaningful science learning. Through the implementation of effective questioning strategies and use of appropriate tools, teachers can facilitate deep discussions and dialogue in the science classroom. Effective questioning promotes active construction of knowledge. It includes open-ended questions, reflective questions, and student-lead negotiating questions that help them consider multiple perspectives about a problem and learn to craft sophisticated arguments. Teachers also need to transform classroom management and shift away from authoritative monologic discourses towards more dialogic teaching and relevant and student-centred activities.

Challenges

Some educators will find it complicated to implement a socioscientific issues-based instructional framework and engage students in critical dialogue and robust argumentation due to several reasons that include but are not limited to: mandates of overcrowded curricula; standardized assessments and high-stakes testing that cause time restrictions for teachers; lack of knowledge including conceptual and multidisciplinary knowledge concerned with socioscientific issues and strategical knowledge to teach argumentation and critical thinking; lack of support from school administrators to ensure that teachers have enough resources and tools that meet the learning needs of students; and lack of teacher engagement in professional learning communities and collegial cooperative interactions to manage curriculum content and design relevant and responsive science educational experiences that prioritize responsible citizenship goals to promote intellectual and character development.

Future Implications

This research implies a critical analysis of Grade Seven, Eight, and Nine science curricula in terms of curricular content and objectives to investigate how teachers can incorporate transformative learning themes and experiences through the lens of the examined theoretical perspectives. Of course, proper scaffolding of conceptual learning and higher-order thinking to meet the needs and capabilities of students and curricular requirements is strongly demanded. In addition to that, adequately designed assessments regarding socioscientific issue discussions and arguments and the sociopolitical, economic, and ethical implications of science and technology need to be developed.

Conclusion

Science is deeply embedded in personal and public decisions. The modification of our society and natural environment entails treating science as a human and social endeavor to transform our realities and foster social justice and sustainability of our natural environment. In my thesis, I argued for the need to shift science education in schools away from the static, depoliticized and decontextualized model of teaching and learning towards a more relevant, inclusive, and responsive framework that advocates for the goals of critical scientific literacy and responsible citizenship. The risks and uncertainties manifested in our societies and environment demand active, critical, and responsible future citizens that act as informed decision-makers and agents of change. It is our responsibility as educators to create a science education culture that empowers students to recognize the dark and bright side of scientific and technological advancements and distinguish between reliable information and misinformation to orient their decisions towards aims that strengthen human values, justice, and peace on Earth.

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