Curriculum, Pedagogy, and the Practical: From Waves to Quantum Physics

by

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Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy

in the
Educational Theory and Practice Program
Faculty of Education

SIMON FRASER UNIVERSITY
Spring 2022

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Abstract

This study initiated with the recent changes and challenges of the global pandemic in our life and education. While discussing the reasons for adapting to the so-called ‘Fourth Industrial Revolution,’ the current and future needs for teaching and learning contemporary scientific knowledge and skills are explored. This thesis is an exploratory study of science education for middle or junior high school students that gives reasons for developing a *wave-quantum-curriculum* to support their physics learning in early adolescence (Grades 8–9). Situated in the context of an extracurricular after-school program, the study discusses and illustrates how a teacher develops such a curriculum and utilizes technology and pedagogical tools to engage and encourage young students, particularly girls, to learn mathematical sciences connected to their everyday lives and lived experiences. To this end, I combine theories of various curriculum scholars, the challenging times of the pandemic, and my lived experiences in teaching and learning to create an updated and adapted curriculum and pedagogy of physics from waves principles to quantum mechanics fundamentals. I argue that an early initiation to big ideas and basic concepts in physics not only can develop youths’ initiation in science, but can also inspire further physics learning and continuing interest over time. Broadening girls’ participation and increasing their self-confidence in physics and other STEM-related disciplines are significant aspects of this early initiation. The study includes a demonstration of the effectiveness of simulation-based inquiry learning and the use of technological and pedagogical approaches in teaching quantum physics.

Keywords: Curriculum and Pedagogy; Teaching and Learning; Quantum Physics; STEM Skills; Simulations and Applications; Females’ Underrepresentation

Dedication

This work is dedicated to my daughter, my family, students, teachers, educators, facilitators, and whoever is passionate about creating a change and developing a positive and constructive impact on learning and teaching.

Acknowledgements

First of all, I am especially grateful to God for granting me this opportunity to know myself, to learn from challenges, gaps, difficulties, and pleasant and unpleasant experiences, to act in the most complicated time of my life, and finally to achieve what my God has wanted for me. I am so grateful to God for keeping me alive in seeing and hearing, and finally perceiving his lights. Light of life. Light of knowledge. Light of being and becoming. I am also thankful to the people who have supported me on my journey, particularly during my doctoral studies. As my doctoral thesis reflects my lived experiences and work, I would like to acknowledge and appreciate all of those scholars, committee members, colleagues, and individuals without whose support and inspiration I would not have been successful in completing my studies in this program. Each has had a significant impact on me, and I was very fortunate to have had them throughout this process.

I truly appreciate Dr. Allan MacKinnon, my senior supervisor, who has received the Graduate Studies Award for Excellence in Leadership at Simon Fraser University's Faculty of Education. I'm honoured to have been his graduate student at SFU. He taught me to progress in independent scholarship and supportively provided useful insights and suggestions in the areas of teaching and learning related to my work. He has patiently helped me to know myself and recognize my skills. His positive energy and patience with constructive feedback led me to progress through my studies to discover what I had to realize and learn.

I thank Dr. Sean Blenkinsop, my graduate course instructor and committee member, who highlighted points and issues that I had overlooked in my study. He taught me that sometimes recognizing, shedding light, and focussing on points of interest and strengths or someone's abilities might be more helpful in leading and stimulating rather than criticizing and questioning the gaps and problems. I found him to be an expert in guiding with questioning, and he introduced me to scholars whose work and focus could strongly support my thesis.

I thank Dr. Charles Bingham, my committee member, who enthused me with his views and comments on both my proposal and thesis. His queries reminded me of some significant points and circumstances in my past work and experiences that directly and indirectly affected and shaped my thesis. I found his standpoints extremely encouraging, and I appreciated his insights and feedback on first organizing then developing and expanding a dialogue with my thoughts and beliefs.

I would like to acknowledge and appreciate Dr. Natasa Sirotic, co-founder of Math Potentials, former programs director, and my manager, who built and designed the curriculum of Math Circles Program in BC. She trusted in my knowledge and experiences in the field of science and provided me with an unprecedented opportunity to bring my experiences, knowledge, and practices into Science Circles Program. She let me balance theory and practice in science education and shed light on a general liberal science education. She provided me with a professional, educational, positive, progressive and collaborative working environment in which not only teachers can freely work and use their autonomy to vigorously create constructive pedagogical moments but also in which students are free to demonstrate their intellectually active engagement, learning and innovation away from the stress of exams or assessment tests. Since 2020, she has let me build and design the curriculum of Science Circles Program for youths' physics learning at their early ages.

I would also like to thank Mr. Mario Sirotic, programs director of Math Potentials and my colleague, who has always been responsive and patiently supportive while collaborating throughout the program and supporting young students' science and mathematics learning. He helped me by purchasing and mailing all the required science equipment and materials to every online student and preparing them for me and all in-person students during the COVID-19 pandemic.

I appreciate Catherine Louie, library assistant in the Research Commons at the SFU Library, who was patiently supportive. She was always welcoming and eager to help and respond to not only my questions but to all the students' questions. She carefully checked the format of my doctoral thesis, and even taught me how to format a thesis and correct any issues after sending it around to my committee members.

I would like to recognize Melissa Smith, librarian for the Faculty of Education, who always promptly responded to my questions. She guided me on how to place an interlibrary loan and request resources from other libraries when they were not available from the SFU library. She was always open and welcoming about finding books, articles, and research resources.

I would like to acknowledge and thank Maureen Phillips, my editor, who on occasion kindly spent time with me on the phone where we had great discussions to clarify some of my statements in the thesis as I was trying to interweave difficult scientific and philosophical points. She provided helpful suggestions in various drafts of my thesis and keenly cooperated with me during the editing of my thesis, always welcoming my writings.

A special appreciation and thank you goes to my daughter, Nazgol, and my husband, Shahram, without whose patience, support, encouragement, and cooperation I would not have had the opportunity to simultaneously work for Science Circles Program and complete my doctoral studies at SFU. I appreciate them for supporting me throughout my journey since 2020. They have been wonderful sounding boards, and we have had many constructive and inspirational conversations about my thesis and its related topics which helped me to explore various views and to think of things in new ways.

I appreciate my parents, Fariba and Jamshid, who have always been the first on-board to encourage and support me to pursue my education at the doctoral level. They have always been the first to send me positive and caring thoughts and to uplift me during the writing of my thesis. I appreciate them for supporting me throughout this entire process and for understanding that it was something I needed to do.

To end, I appreciate all the helpful insights, feedback, and critiques explicitly and implicitly given by the people named here. Thank you!

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List of Acronyms

AAUW	American Association of University Women
AR	Augmented Reality
APS	American Physical Society
BC	British Columbia
CCA	Council of Canadian Academies
CC-BY	Creative Common Attribution license
CP	Collaborative Project
DOC	Document
MR	Mixed Reality
NASA	National Aeronautics and Space Administration
NCES	National Center for Education Statistics
NSERC	Natural Sciences and Engineering Research Council
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
PhET	Physics Education Technology
Phyphox	Physical Phone Experiments
PISA	Program for International Student Assessment
SCP	Science Circles Program
SFU	Simon Fraser University
STEM	Science Technology Engineering and Math
STS	Science-Technology-Society
STSE	Science-Technology-Society-Environment
UBC	University of British Columbia
UC	University of California
US	United State
VR	Virtual Reality
WEF	World Economic Forum

Chapter 1.

Introduction

The purpose of this thesis is to critique, reconstruct, and redesign 21st-century physics curriculum and pedagogy for middle, or junior high schools. I explore effective pedagogical factors and the significance of student engagement, participation, and interest in the physical sciences. The main question for this study is *why* would a teacher endeavour to develop a *wave-quantum-curriculum* to support the learning of physics by young students (grades 8 and 9) in a science program during these complex contemporary times? This study also explores *how* a teacher might develop such a curriculum to engage and encourage these students, particularly girls, to learn physics concepts connected to their everyday lives and lived experiences.

Lived experiences in education, through teaching and learning (with all their fundamentally relational aspects) in the past and currently, are a worthwhile focus for development (Pinar, 2019; MacKinnon & Moerman, 2016). According to the OECD (Organization for Economic Cooperation and Development) Education Directorate, “What we learn, the way we learn it, and how we are taught is changing. This has implications for schools […]” (Schleicher, 2010, p. 2). The ongoing pandemic, starting in 2020, has changed education and provided us with opportunities to rethink, redesign, and reconstruct future education in which technology and digital devices could vastly support students and teachers during these complicated times (Schleicher et al., 2021; Schleicher, 2020; OECD, 2021b).

“We are at the beginning of a revolution that is fundamentally changing the way we live, work, [study, learn,] and relate to one another” (Schwab, 2016, p. 7). It is the time of the Fourth Industrial Revolution (Schwab & Davis, 2018; World Economic Forum, 2020c; Schwab, 2016, 2017; Reaves, 2019; Philbeck & Davis, 2019) when the world is in the process of understanding and shaping a new technology revolution with a profound and systemic change towards digitalization and technology (Schwab, 2016; Reaves, 2019; Schleicher et al., 2021; Schleicher, 2020; OECD, 2020C, 2021b) while it is dealing with crises and now COVID-19 pandemic. “Living at the beginning of the Fourth Industrial Revolution means we bear a huge responsibility to ensure that the technologies changing the world do so in a way that reflects common values and delivers broad-based benefits” (Schwab, 2018, p. 14).

Reforming the ways of seeing, thinking, learning, teaching, and acting during these challenging conditions is the first rational step toward progress and, finally, success as these challenges will be converted to new possibilities and opportunities in various sectors in the future. It is important to know that there are many ways and approaches to support students’ science learning through this tough journey and continue toward progressive and constructive learning. My approach is based on a big assumption—the *Fourth Industrial Revolution*; is determined through a self-study; is integrated with a big idea—*wave-quantum-curriculum*; and is practised by myself as a female science educator in a science program. Through this approach, I first review the recent changes and challenges due to the COVID-19 pandemic in life and subsequently in education which, in the future, might be counted as part of a revolution, the Fourth Industrial Revolution (Schwab & Malleret, 2020). We need to know and understand what the Fourth Industrial Revolution is, how it impacts our current and future education and everyday life, and how we might need to adapt and update curricular and pedagogical approaches in teaching and learning to respond and survive through it (Schwab, 2018, 2017; Schwab & Davis, 2018). Past and current scholars will help us through this uneasy journey. As such, for restructuring, we must first conceive of the needs and infrastructures as a whole, and then proceed according to current circumstances.

More digital objects and devices will accompany us by being connected to our bodies and our everyday lives (Schwab & Davis, 2018; Arnault, 2014; Schwab, 2016). Quantum-based devices, quantum-based solutions, the quantum internet and quantum networks using (based on) quantum mechanics will soon be available (Preskill, 2019; Valivarthi et al., 2020; Kimble, 2008; Wehner et al., 2018; Yin et al., 2017; Harney & Pirandola, 2021; Brito et al., 2021; Nielsen & Chuang, 2010; Briegel et al., 1998). As such, not only an awareness and desire by young students to prepare for a new technological and digital future are needed (NSF, 2020, 2008; NSERC, 2021, 2010; CCA, 2015; Science, Technology and Innovation Council, 2015), but also curricula and pedagogical updates and adaption are required for acquiring such knowledge and achieving our goals in the future (Elbeck, 2018; World Economic Forum, 2022, 2020c; Science, Technology and Innovation Council, 2015; DeCoito, 2016). I attempt to shed light on the main reasons and key issues that can stimulate a teacher to focus on teaching physics concepts, which will lead adolescents towards learning quantum mechanics. I also propose approaches on how to develop an adapted and updated curriculum—*wave-quantum-curriculum*—and how to teach the most complicated concepts and topics of physics while engaging and encouraging young students, particularly females, in physics.

1.1. Problem Statement

School science, relatively independent from the science of scientists, has been popularized during the last century (Izquierdo-Aymerich & Adúriz-Bravo, 2003). In the 21st century, the Fourth Industrial Revolution is impacting everything—life, education, business, and so forth (Schwab, 2016, 2017, 2018, 2021; Schwab & Malleret, 2020; Philbeck & Davis, 2019; Schwab & Davis, 2018). Institutes such as the National Science Foundation (NSF) (2020, 2008) in the United States; Natural Sciences and Engineering Research Council of Canada (NSERC) (2021, 2010); Science, Technology and Innovation Council's State of the Nation (2015) in Canada; Council of Canadian Academies (CCA) (2015); and OECD (2020b) underscore the urgency for adolescents to learn STEM skills and related knowledge to become prepared for the future. Subsequently, responding curricula and pedagogical tools and approaches that can mainly encourage and support youths' science learning and interest in scientists' science is necessitated (DeCoito, 2014, 2015b, 2016; OECD, 2020b; World Economic Forum, 2020a). With the high-paced industrial revolution, "educational curricula cannot remain fixed as career paths change faster, and are less linear, than ever before" (World Economic Forum, 2020a, p. 14). Scholars (Tytler et al., 2008) argue that reframed STEM-related curricula may nurture youths' creativity and ambition while the problem of declining interest in STEM and decreasing enrolment rates is noticeable (Amgen Canada and Let's Talk Science, 2019, 2012; DeCoito, 2016, 2015b; NSF, 2020; NSERC, 2021).

Moreover, the COVID-19 crisis is vastly impacting our education, daily lives, and future career paths while requiring adaptions and new approaches of teaching and learning not only for the current status quo but also for the future (Schwab & Malleret, 2020; OECD, 2020b, 2020C, 2021b, Schleicher, 2020; Schleicher et al., 2021)—a future that will predominantly rely on technology and science. Most professions of the future will require a basic understanding of science, math, and technology (OECD, 2020b;

DeCoito, 2016; Science, Technology and Innovation Council, 2015; NSF, 2020, 2008; NSERC, 2021, 2010) since STEM skills and scientific knowledge are the backbone of the Fourth Industrial Revolution (Philbeck & Davis, 2019; Schwab & Davis, 2018; Schwab, 2016). Studies show that rethinking, reshaping, reconstructing, and transforming is needed in education to adapt to the Fourth Industrial Revolution (World Economic Forum, 2020a, 2020c; Schwab, 2021) and empower students today and tomorrow (OECD, 2021b; OECD, 2020C; Schleicher et al., 2021; Schleicher, 2020; Schwab, 2021; DeCoito, 2016).

People with high motivational beliefs about a field or an area, according to the expectancy-value theory (Wigfield & Eccles, 2000), are more likely to stay in that field or area and thrive (Wang et al., 2017; Liou et al., 2021; Hsieh, Liu, & Simpkins, 2019). "Motivational beliefs" are associated with *interest* (how enjoyable), *utility* (how useful), and *ability self-concept* (how good), as described by the expectancy-value theory (Hsieh, Liu, & Simpkins, 2019, p. 2). As such, students with elevated motivational beliefs in science are more likely interested in contributing to science classes and pursuing studies in the field of science (Wang et al., 2017; Liou et al., 2021; Buday et al., 2012; Hsieh et al., 2019). Not only do "middle and high school students' motivational beliefs differ based on the specific science subject" but also "collapsing biology, chemistry, and physics into 'science' could mask the differences youth see in these subjects" (Hsieh et al., 2019, p. 2). The results of their study demonstrate that there is a "need to differentiate both among science subjects and among motivational beliefs" (p. 10). Moreover, students, on average, are more interested in learning science at early ages and at middle school levels, Grades 6–9 (Bennett & Hogarth, 2009; Hsieh et al., 2019). However, for various reasons, they lose interest and place a higher value on other subjects after that (Bennett & Hogarth, 2009; Hsieh et al., 2019; Amgen Canada and Let's Talk Science, 2014), when their interests respectively shift to biology, chemistry, and physics (Bennett & Hogarth, 2009; Kahn & Ginther, 2017; Hsieh et al., 2019; Amgen Canada and Let's Talk Science, 2014). Young female students' interest, motivational beliefs, and preferences, in comparison with young male students, decrease at a faster rate for physics in Grade 9 (Hsieh et al., 2019; Kahn & Ginther, 2017). Since physics becomes the least preferred subject in science over time, it appears that the best time to support and guide students' beliefs, interests, and knowledge in physics is in Grades 6 to 9, exactly when they are interested in it.

There are consequences not only for females in the field of physics but also for the field of physics itself, as “the highest number of young women who choose to reject physics do so at a high school level in Canada” (NSERC, 2010; Mainhood, 2020, p. 51). I, as a female educator, identify seven problems in the field of physics that resulted in problematic situations in science education for this subject, which I call an *abandoned subject* in science, particularly by females. First, recent changes and challenges due to the crisis of COVID-19 require new approaches and adaptions in education (Schleicher et al., 2021; Schleicher, 2020; Schwab, 2021; OECD, 2021b, 2020c). Second, “Learning courses [particularly physics] are too infrequently updated, and too often not adapted to the Fourth Industrial Revolution” (World Economic Forum, 2020a, p. 14). Third, adolescents (females and males) do not pursue their studies in STEM and believe that these subjects and fields are not suitable for them (Amgen Canada and Let’s Talk Science, 2012, 2019; Francis et al., 2017; Archer et al., 2012; Brown et al., 2008; Hutchinson & Bentley, 2011; Institute of Mechanical Engineers, 2010; Larson, 2014; Lewis et al., 2009; Tripney et al., 2010; Hyde & Lindberg, 2007). Fourth, females are underrepresented in physics (Natural Sciences and Engineering Research Council of Canada, 2010; American Physical Society, 2015; Baram-Tsabari & Yarden, 2008; Kahn & Ginther, 2017; World Economic Forum, 2021b) and overrepresented in biology (Hsieh et al., 2019; National Science Foundation [NSF], 2017; Ceci et al., 2014). Fifth, “overall ‘science’ [in the lower grades like 6 to 10] … fail[s] to represent the nuances that each subject offers” and “collapsing multiple science subjects” is problematic (Hsieh et al., 2019, p. 3). Sixth, there is a lack of specialized physics teachers with physics background knowledge not only at the lower grades but also at the higher grades in high schools (APS, 2021; National Center for Education Statistics [NCES], 2016; White and Tyler, 2014; Meltzer et al., 2013; Ogodo, 2019; Hill & Gruber, 2011). Seventh, the impact of the science teachers’ subjectivity (having interest and content knowledge in other fields of science, not in physics) on students’ interests and preferences towards the subject of physics is significant (APS, 2021; NCES, 2016; Banilower et al., 2013; Hill & Gruber, 2011).

In short, the aforementioned issues are problematic. No studies argue the impacts of the Fourth Industrial Revolution on curriculum and pedagogy. Nor do they argue the attempts by teachers and educators to update and adapt these approaches to the Fourth Industrial Revolution for the aim of supporting young students’ physics learning. There are numerous studies related to young pupils' science and mathematics learning and teachers teaching at extracurricular and enrichment after-school programs (DeCoito, 2014, 2015b, 2016) but not specifically focussed on youths' physics learning towards quantum mechanics at an early age (15 to 16 years old) as well as teachers' planning for such learning at a science program.

1.2. Purpose

> *Having a goal—interpreting the world and intervening on it—and progressing towards this goal through decision making are the most important characteristics of any rational human activity.*
>
> *(Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 30)*

The quality of education and its effects on students who are going to create and improve the future is one of the most important points involving history, politics, human nature, society, culture (Harris, 1999, Pinar, 1978, 2019), and economics. There are diverse voices in formulating and legitimizing the aims of education, some of which dominate. It is significant to identify whose "aims" and "destination and ends" are respectively propounded, formulated, legitimated, and implemented in education and society. STEM fields act as drivers in every social and economic growth where the National Science Foundation (NSF) (2020, 2008) in the United States, Science, Technology and Innovation Council's State of the Nation (2015) in Canada, Council of Canadian Academies (CCA) (2015), the Natural Sciences and Engineering Research Council of Canada (NSERC) (2021, 2010) emphasize and encourage to develop and implement educational STEM initiatives to enhance young students' interest and develop their skills in STEM for the aim of being prepared for the future careers and available job markets. Consequently, the main purpose of this study is to redesign an adolescents' physics learning path for a Grades 8–9 extracurricular science program and develop a physics curriculum (*wave-quantum-curriculum*), and encourage and engage youths, particularly girls, to build their knowledge of a mathematical science, physics.

In *Aims! Whose Aims?*, Harris (1999) not only demonstrates the relationship between state and educational policy but also illustrates the penetration and power of the state in implementing policies. He connects this relation to economic and capital accumulation, which is critical for any society (Harris, 1999). Different countries with diverse governments justify the aims of policies according to their own interpreted and determined benefits whether based on religion, tradition, culture, or (social and economic) crisis. The point here is that the aims of education may be aligned with the aims of state for the purpose of "providing leadership and stability … at a time of social change and fiscal crisis in … [country]," for example (p. 10).

Not only education but *research* will also be seen "as an inescapably political as well as intellectual act" (Pinar, 1978, p. 210). In this study, I intend to stay away from political issues and states' educational affairs, and public schools and private schools with their governmental structures, systems, and agendas as they are not the focus of this study. In short, as stated by Pinar (2019), "What remains from education is the cultivation of 'original thought' while attentive to one-self and others" (Pinar, 2019, p. 15).

Before stating the objectives of this study, I must acknowledge that I have been provided with unprecedented opportunities through this study by the challenges, difficulties, and crises of 2020. These challenges have encouraged and caused me to study myself, review my skills and experiences, to be more persevere, and adapt after about 20 years of studying and gathering experience in science, business, and education. I am going to write about some of these changes, opportunities, actions, and practices that helped me to develop a physics learning path for adolescents. I will explicitly and implicitly shed light on the opportunities that will be utilized as well as on the gaps to be addressed and erased in the future, not only for teachers but also for young students. I strongly believe that traditions set boundaries, so the boundaries need to be broken, using creativity and innovation to fix those traditions. I break boundaries, standards, and traditions in this paper, for example, for writing and being limited to one dimension of curriculum and pedagogy, either on the student side or the teacher side, as Tanner believed about John Dewey's work (Tanner, 1991). I deliberately involve both sides in my arguments since I am studying myself as a student and teacher. I will focus on the two most critical aspects of education: curriculum and pedagogy. I will bring in several theoretical perspectives to form an eclectic framework. This eclecticism will enable me to achieve my goals, as each of the perspectives I introduce has a different standpoint. I will depict how these views let me develop my understanding and create ideas, how past and current scholars' perspectives, such as John Dewey, Joseph Schwab, Ralph Tyler, William Pinar, and Ted Aoki, helped me build my study. I will shed light on those viewpoints (even the scholars whose views have been under critique or in conflict) integrating other scholars' views in my study in 2020, and will speak about the huge changes, challenges, and opportunities.

I will refer to our recent lived experiences, changes, and diverse circumstances due to the COVID-19 crisis in our life, education, and career (Schleicher et al., 2021; Schleicher, 2020; OECD, 2021b, 2020c; Schwab, 2021; Schwab & Malleret, 2020). I will have an unexpected assumption in my study which is totally new terminology to us, the Fourth Industrial Revolution (Schwab, 2016, 2017, 2018; Schwab & Malleret, 2020; Philbeck & Davis, 2019; Schwab & Davis, 2018). This study is initiated with an extensive review of literature and research about the changes, challenges, and needs in the current and future education and subsequently in future career paths (NSF, 2020, 2008; NSERC, 2021, 2010; DeCoito, 2014, 2015b, 2016; Schleicher et al., 2021; Schleicher, 2020; OECD, 2021b, 2020c, 2020b; Schwab, 2021; Schwab & Malleret, 2020; Science, Technology and Innovation Council, 2015), and what the Fourth Industrial Revolution will be bringing to us in the future (Schwab, 2016, 2017, 2018, 2021; Schwab & Malleret, 2020;; Philbeck & Davis, 2019; Schwab & Davis, 2018). I will carefully explain what the Fourth Industrial Revolution is and how it impacts our life, education, and jobs in the future. With this critical standpoint and important assumption, I attempt to develop and design a physics curriculum (*wave-quantum-curriculum*) which will support and respond to some of the youths' science learning needs as well as the changes in the future.

I seek not only to explain *why* I developed wave-quantum-curriculum to encourage youths in an extracurricular enrichment science program during the COVID-19 pandemic, but also *how* I can develop that curriculum and engage adolescents, particularly females, to learn physics concepts and build a background knowledge towards quantum mechanics while adapting contemporary issues, connecting to their everyday lives and experiences in this field of science. Young students (Grades 6–9) can learn physics not as a school subject and a required course in their formal education but as *scientific knowledge*, as indicated by OECD and other scientific centres, for living and working as prepared science-aware citizens toward a more sustainable future, to thrive in the modern workplace and in their future careers (OECD, 2020b; NSERC, 2021, 2010; Science, Technology and Innovation Council, 2015; NSF, 2020, 2008; DeCoito, 2016).

I review studies that address how educators and students can adapt to the Fourth Industrial Revolution (Schwab, 2021, 2016, 2017, 2018; Schwab & Davis, 2018; Schwab & Malleret, 2020). I will review the current resources that may suggest meaningful reasons to update the current curriculum and pedagogy to the Fourth Industrial Revolution (World Economic Forum, 2020a; Schwab, 2021). I, as a female science educator, will also highlight the issues and gaps related to women's underrepresentation in STEM, particularly physics (Hussénius, 2020; NSF, 2016, 2017; Robnett & John, 2020; World Economic Forum, 2021b; Francis et al., 2017; Kahn & Ginther, 2017; Archer et al., 2017; DeCoito, 2016; AAUW, 2010, 2015; Ceci, 2014). A lack of role models and lack of opportunities for females, and consequences of gender disparity in physics will be explicitly argued (Barker, 2018; Weber, 2011; Milner-Bolotin, 2015; Sandberg, 2013). The reasons that result in less participation and interest of girls in STEM will be mentioned. Furthermore, I will refer to research studies that suggest the use of digital technologies engage and motivate students, enhance their appreciation of content learning, and revolutionize ways of learning and teaching methods (Milner-Bolotin, 2017a; PhET, 2021; Buckley et al., 2021; McKagan et al., 2008; Fox et al., 2020). By my actual practices in science classes, I will illustrate how the use of technological pedagogical tools may support both teachers and students in physics *wave-quantum-curriculum* in SCP.

This study does not inquire into all the scenarios related to a lack of interest by teachers and students in the subject of physics. There are many aspects, factors, and elements that influence students' and teachers' preferences and appreciation for learning and teaching physics subjects which are not the focus of this study. It is important that the aim of this study is not to delve into and discuss all aspects of curricular changes (curriculum transformations), all other possible negative factors associated with physics and physics learning, the negative aspects and impacts of the Fourth Industrial Revolution, automation, and digitalization on education. This study focusses on the positive and efficient factors, aspects, and impacts of the Fourth Industrial Revolution and curricular and pedagogical changes. It focusses on an updated and adapted curriculum—*wave-quantum-curriculum*, on students learning about physics and contemporary scientific problems in the 21st century, and the positive and constructive effects of an educator's attempts in these regards.

I will review and examine past and current research evidence and scholarly resources through an extensive literature review in the field of education, curriculum and pedagogy, K-12 education, and science education, particularly physics, primarily in the US, Canada, and elsewhere if needed. I will also consider the publication dates of the scholarly resources. Seminal pieces published preceding the year 2000 beside up-to-date resources will be considered and utilized in my study. It is significant that student and teacher demographic factors such as class, race, and socioeconomic status are varied and are not variables to be considered in my study.

1.3. Research Questions

With the current status quo and COVID-19 crisis, so many questions have been raised about education and technologies and whether educational curricula have been updated and adapted to the Fourth Industrial Revolution by only utilizing technologies in the classrooms. To what extent, from a pedagogical perspective, has technology helped us become updated? To what extent are we successful in shifting our traditional ways of teaching and our pedagogical approaches in physics and mathematics classrooms? To what extent are the students engaged in their own process of learning by our providing them with opportunities to have active roles virtually? To what extent are we, teachers, allowing students to learn throughout collaboration and deliberation in classrooms? To what extent is the curriculum, with our pedagogical approaches in classroom teaching, helping students improve upon the required skills of the 21st century such as problem-solving, critical thinking, creativity, collaboration, and digital literacy? And finally, to what extent could we adapt and update ourselves (our curricula and pedagogical approaches) with the high-paced Fourth Industrial Revolution and the recent shifts in education? The same kinds of questions could be addressed to the curriculum and pedagogy. Therefore, to help and support students' learning throughout this transition and revolution from physical classrooms to virtual ones and the use of technologies, the key questions to be explored in this study are strongly related to curricular changes or curriculum transformation, updates with contemporary pedagogical tools, and diversion of the theoretic to the practical by specialists. To sum up, the main research questions of this study are as follows:

1- Why would a teacher/educator endeavour to develop *wave-quantum-curriculum* to support young students' physics learning at their early ages (Grades 8–9) in a science program during our complex contemporary times?

2- How can a teacher/educator develop the curriculum, engage and encourage adolescents (at the early ages of 15–16 years old), particularly females, to learn physics concepts connected to their everyday lives and lived experiences?

The questions will be answered according to a synthesis of the perspectives of scholars in curriculum studies on learning and teaching in education, with John Dewey's views about a hands-on approach, lived experiences, and collaboration; Joseph J. Schwab's standpoints on practical theory, curricular reform, and deliberation; Ralph W. Tyler's perspectives on educational objectives and significance of contemporary life, and William Pinar's autobiographical method of *currere*, "self-study," "self-understanding," "self-realization," "self-affirmation," "self-mobilization," by returning to the past experiences and imagining the future. "Each is reliant upon the other," as stated by Pinar (1978). The questions will be followed by a literature review, self-study, and my individual observations, actions, practices, and lived experiences.

1.4. Organization and Overview of Thesis

In Chapter 1, *Introduction* of the dissertation, I presented the *problem statements* of the study, and next explicitly stated the *purposes* of this dissertation. The main *research questions* of the thesis were posed respectively. In the end, I outlined the way that this thesis has been organized and how the chapters have been written through the whole dissertation.

In Chapter 2, *Scholars' Perspectives in Science and Curriculum Studies and My Philosophies,* while I applied Pinar's method of currere by going to the past for preceding scholars and returning to the present for contemporary ones, I introduced the curriculum theorists whose theories and inspirations have influenced my thinking, and whose work helps to situate the thesis in curriculum studies and science education. An eclectic approach in my theoretical framework helped me build the study from various dimensions: importance of contemporary life and its associated objectives, importance of transformation due to new objectives in the current life, importance of contemporary knowledge and skills, importance of collaborative and active learning approaches besides lived experiences, and importance of being able to convert the theoretic to practical.

In Chapter 3, *Need for Reform During the Fourth Industrial Revolution*, I provide a review of relevant literature and extant resources that demonstrate the *need for rethinking and reforming in education due to the Fourth Industrial Revolution* as well as the supportive literature for the discussions and arguments made in the study. I initiate with an argument about *changes* in our *contemporary life* while bringing scholars' perspectives on *how to adapt to these changes and challenges to maintain our well-being and mental health.* I continue with exploring the main scope of the *Fourth Industrial Revolution*, reasons for updating and adapting our approaches to the Fourth Industrial Revolution to manage impacts on our future when the importance of integration of ontology, epistemology and ethics in science is necessitated for a more sustainable future. This chapter ends with my *first important conclusion* for *new initiations* in the rest of this study which is fundamentally built on top of the assumptions and discussions made in this chapter.

In Chapter 4, *My Perceptions of Gender Equality and Equity as a Female Science Educator in the Field of Physics*, I, as a female science educator, shed light on a longstanding gender issue in STEM, particularly physics, while reflecting my insights and referring to my own experiences in the field of mathematical science. I first determine *ways of seeing* and their impacts on our knowing, being, and becoming. Then, I start *scanning and detecting the gender gap problems in STEM*, not only throughout history but also in my lived experiences to become able to be part of initiations that might enhance gender equality and equity in physics. Thus, I conclude the chapter with plans and progresses proceeding to remove the barriers to females' participation in physics.

In Chapter 5, *My Experiences: From Theory to Practice*, according to my assumption and argument in the second chapter and gender problems in the third chapter, I, as a female educator in the field of physics, pragmatically act during a complex contemporary time and attempt to become part of new initiations and updates towards a new and more sustainable future. This chapter is a demonstration of a focal point where some of my curricular and pedagogical approaches, experiences, practices in the fields of education and physics, and scholars' theories are converged to create an adapted curriculum—wave-quantum-curriculum— and pedagogy while considering the circumstances mentioned in prior chapters. I illustrate my efforts and approaches for engaging and encouraging adolescents, particularly females, for the aim of enhancing their participation and interest in learning physics, not as a school subject but as required scientific knowledge and skills for 21st-century achievements. This practical chapter is concluded with the results of my studies, observations, actions, and practices from past to present. Moreover, I include some related empirical points for further potential research can be emanated from the study to learn about young students' perspectives about the science program and the designed *wave-quantum-curriculum*. The extent to which the planned learning path has succeeded in supporting their science learning.

Chapter 2.

Scholars' Perspectives in Science and Curriculum Studies and My Philosophies

2.1. Overview of Theoretical Framework

I expand my theoretical framework to more than just one theorist. I apply Pinar's method of currere in my study, even as I select theorists and scholars whose perspectives would strengthen my thesis or on whose work I would build my thoughts. I go to the past and scan the history of education and detect Ralph Tyler's views in *Basic Principles of Curriculum and Instruction* in 1949*.* Tyler emphasizes "the value of the contemporary life to identify learning objectives" in education like *contemporary knowledge, skills, and abilities*. The significance of determining the *learning objectives* is still being used not only in education but also in other professions. Reading Tyler's work was the moment that I became more interested in the old scholars who seem to be more focussed on the significant fundamentals and factors in education.

Therefore, I went back further in history where I discovered the most helpful approach of a pragmatist and progressive, John Dewey, in learning science. His perspective on considering *lived experiences* and connecting them to content learning besides having *hands-on activities* while *collaborating* with peers inspires every science educator and teacher. Carefully looking at Dewey's theory of learning with a student-centred approach and our contemporary life in 2020, new curricular and pedagogical approaches seem to be needed to adequately plan for learning objectives of adolescents' future education. As such, my research leads me toward a transformative perspective and a new direction for curriculum. This is where we can be selective in curriculum, as with Joseph Schwab, whose view of deliberation and practicality in curriculum could be complemented with Dewey's view of collaboration and actual practices. To practice, I return to the contemporary and carefully imagine the future of education where I need an autobiographical framework to bring my narratives of practices and experiences of teaching and learning into my study, while still applying William Pinar's method of currere.

After selecting and learning the essentials in curriculum studies with older theorists in the past (according to Pinar, the regressive moment), I am now paying attention to the contemporary life (quantum time). I think about the future and progress of science education for youths' physics learning, the progressive moment, toward quantum mechanics (He et al., 2021; Venegas-Gomez, 2020; Akdemir et al., 2021; Franklin et al., 2020a, 2020b; Krijtenburg-Lewerissa et al., 2017). I, as a female science educator, select a contemporary female theorist in science, particularly in quantum physics—Karen Barad. Not only does she problematize the patriarchal, male-dominated environment in the field of physics but also believes that not all questions in the theory of quantum have been answered by physicists in the field. Some questions in quantum have been left to philosophers and philosophical perspectives in social sciences (Barad, 1995, 2007; Vermaas, 2017). She unequivocally emphasizes ethical uses of scientific knowledge and ethical ways of knowing and being in science, particularly in modern physics and knowledge of quantum mechanics (Barad, 2007).

Responding to my conceptual and practical questions in this study requires a vast theoretical framework that needs to embrace different theorists' perspectives in education. The theorists might have reached a consensus in some aspects of learning and teaching; however, the scholars that I have selected do not hold many views in common. Every scholar's view supports one aspect and angle of my study, so each scholar will be utilized for a particular point of view. Not only have I been selective in my theorists, but I have also been selective in their perspectives. Choosing a theorist does not necessarily mean that I have considered and accepted all their perspectives. This eclecticism in the theoretical framework provided me with a constructive framework and various needed supportive standpoints from theorists in this study. I either directly apply the scholar's point of view or utilize it as an infrastructure to build my own philosophy in the work. Each of the following support my study from various perspectives: Tyler's view on educational goals and emphases on the importance of contemporary life; Dewey's focus on students' collaboration, their lived experiences, and hands-on approach in learning; Schwab's practical theory, emphasis on deliberation and curricular transformation; Pinar's autobiographical approach; and Barad's philosophical, ethical, and scientific viewpoints on quantum physics.

In brief, I, as a pragmatist, progressive, and at some points essentialist, will attempt to utilize standpoints and theories that provide a comprehensive framework for this study. I will refer to my own experiences—past, present, and future—as well as my own teaching and learning practices in education. As such, an autobiographical approach referring to my lived experiences as a science student, physics teacher, and science educator will be explicitly and implicitly traced with help from William Pinar.

2.2. John Dewey

> *Dewey argued that children are inherently active, with the strong impulses to investigate, to share with others what they have found out, to construct practical things, and to create. Dewey Developed this psychological concept into a curriculum principle: the child's impulses are an enormously important educational resource and opportunities should be provided for children to help them through engagement in activities.*
>
> *(Tanner, 1991, p. 44)*

John Dewey (1859–1952) defines education as the process of living through a continuous reconstruction of experiences. In other words, our lived experiences may explicitly and implicitly teach, nourish, and mould us in the school of life. This is the actual reason for the surprising result in Coulter and Wiens's (2009) research activity regarding the "educated person." How we interpret "education" and subsequently the "educated person" in our society is critical and controversial in our everyday lives since we reflect and refer to our own acquired experiences to define and describe an educated person (Coulter & Wiens, 2009). This controversy illustrates the existence of a proportional relationship between our lived experiences and *education*, which was emphasized by Dewey.

However, the aforementioned delineation is not the only definition of "education" (Smith, 2005). Each scholar interprets it differently—diverse aspects of education with various perspectives—accorded exactly with acquired experiences associated with their own circumstances and concerns in their own society. For example, Indira Gandhi believed that education liberated us and allowed us to live in a democratic society in which people were not judged by their class or other prejudices. Moreover, anyone who has watched the "Schooling the World 2010" documentary video will testify that "education" and the "aim of education" differs from one society to another. Some definitions reflect the spiritual and intellectual aspects of education, while others reveal the political, scientific, economic, business and societal/social phases of education. In a democratic society, "Education is like 'democracy' or 'culture' in being what some have called ‘an essentially contested concept’” (Smith, 2005, p. 1). Consequently, each state creates a specific agenda as “education” is rooted in politics, economics, and business. Thus, definitions vary from one state to another.

Both progressive and traditional education should be integrated; it is not just merely an emphasis on experience (Ayers & Schubert, 2012), theory to practice and vice versa. Education in Dewey’s viewpoint is “that reconstruction and reorganization of experience which adds to the meaning of experience, and which increases ability to direct the course of subsequent experience” (Dewey, 1916, p. 76). Which kind of experience does Dewey imply? Sitting, listening to lectures, and doing tests are not the experiences that build students’ experiences to direct the course of their succeeding experiences (Ayers & Schubert, 2012). In other words, “education should be about having students engage with teachers, asking the questions of what’s worth knowing and learning and doing and being and becoming” (Ayers & Schubert, 2012, p. 11).

Dewey follows two significant and fundamental questions in his progressive education: “What kind of life can and should I create? And why?” (Ayers & Schubert, 2012, p. 11). He does not agree with competitiveness either nationally or internationally since the competition, which is based more on testing, is not a worthwhile purpose for education (Ayers & Schubert, 2012). He argues “because the people in power have an agenda that’s somewhat different” (p. 17). Therefore, “there is no way to discover what is ‘more truly educational’ except by the continuation of the educational act itself. The discovery is never made; it is always making” (Dewey, 1929, 76–77; Ayers & Schubert, 2012, p. 18). That is, achievement depends on *action* and movement with justice and peace. He believes that education is a democracy, which with *participation* and *engagement* brings righteousness and peace for the human being.

I attempt to discover an adapted and updated physics learning path with our *contemporary life* by trying, by practising, by failing, by repeating, and by working on curriculum problems. I overtly agree that students and teachers should create the curriculum together according to not only students’ interest and appreciation of learning objectives but also specialist teachers' discretion. Tanner believes that Dewey's curriculum has two dimensions: the student’s side (activities) and the teacher’s side (subject matters). Dewey emphasizes the psychological aspect of curriculum as well as the psychological nature of the child. It is significant that young students “are inherently active" and have intrinsically "strong impulses to investigate," to share, to construct, to create, and to learn, according to Dewey's standpoint (Tanner, 1991). Therefore, youths inherently seek opportunities and activities which match their own innate momentum. When this match occurs, the youth will utilize the inherent "strong impulses" and will be interested and finally engaged in activities. However, Dewey believes that all of these would not occur without students being provided with *opportunities* to engage in activities (Tanner, 1991). Dewey's theory of learning underscores that the individuals' direct personal experiences in activities have a significant role in learning outcomes (Dewey, 1916). Here, I raise a question: *Who would provide such opportunities emphasized by Dewey that would help youths' engagement in activities?*

The point here is whether the subject itself can create the child's interest or "the child's interest must be inherent in the subject matter," as asserted by Tanner (1991, p. 48). I believe there are other relational factors influencing the interest and preference in the subject matter—*who,* with *which* background knowledge, teaches *what* subject of science? "Psychology, like physics and the other sciences of nature, uses the method of induction, which starts from facts and then assembles them" (Merleau-Ponty, 1964, p. 58; Flinders & Thornton, 2017, p. 138). Thus, one's background knowledge and consciousness may have influences on the development of the child's interest and preferences in the future.

It is not a question of how to teach the student physics but first a question of *what physics is for the student*. How and who introduces and describes physics? Passionate specialist (specialized) teachers can subsequently inspire and engage students in the discipline not only by designing constructive activities and learning opportunities but also by their own presence as a proper role model, particularly for females. As underlined by Dewey (1902), teachers need to start with the subject field and plan activities for progressively more complex understandings. Specialized teachers with passion can vigorously get students interested and even excited about what they are learning in physics since they care about students' learning as well as the subject and discipline of physics (APS, 2021; NCES, 2016; Ogodo, 2019; Banilower et al., 2013; Hill & Gruber, 2011; White & Tyler, 2014; Meltzer et al., 2013). The subject and curriculum should not be just a collection of facts and principles which are being only learned with a *read and write* learning approach. It should also be "a form of living personal experience" (Tanner, 1991, p. 42) in which students can kinaesthetically explore concepts. According to

Dewey’s view, students need to be able “to translate abstract knowledge into the concrete form demanded by practical life” and “to deal with more complex concepts in the subject area later” (Tanner, 1991, p. 42). Moreover, students understand and appreciate content learning best if they experience it in the real context of their lives as a form of demonstration, something visualized (Mayer & Alexander, 2011, 2016) and related to their everyday lives (Vygotsky, 1978; Pugh & Phillips, 2011). Teachers and educators should emphasize the necessity for better understanding rather than memorizing basic physics concepts for better tests (or any other competitions) results. Students need to be provided with the opportunities in their learning to get an idea of what physics really is and its application instead of simply and formally receiving and reading the abstract relationships and principles of physics. We should let the students “see that physics is not fixed or static but that it evolves from the inquiries and basic research of scientists” (Goodlad, 1964; as quoted in Flinders & Thornton, 2017, p. 66). Students should be provided with opportunities that let them place themselves in such inquiries and basic research conditions and let them act like scientists. These are all the teacher’s responsibilities.

There is no doubt that a specialized teacher can not only develop students’ understanding of concepts and principles in a discipline better than a generalist teacher but also can plan more focussed, intellectually constructive activities related to students’ daily lives (Tanner, 1991, p. 51). It is a reality that “no one can be an expert in every field of knowledge,” which was demonstrated by and learned from Dewey's Laboratory School. Moreover, Dewey argues that “instruction by a specialist should begin in the first years of school” (p. 51). Working with subject specialists should not be inferred to propose “too technical and too specialized” courses for youths in K-12 education; however, the subject specialists should attempt to make the subject and field more understandable and feasible for adolescents who might be interested in becoming specialists in their field. To sum up, a passionate specialist teacher would provide pupils with opportunities and activities to engage their minds (Dewey, 1902; Tanner, 1991).

Important questions can be raised here in 2021: Why did Dewey's Laboratory School at the University of Chicago not continue and worked only from 1896 to 1904 but Dewey's projects and work at the school still are models for countless scholars and practitioners like a lab in Minnesota? Why did Pinar claim in 2019 that we are lost in education today? The answers to these questions can be traced to both Dewey’s and

Pinar's perspectives in education. The reasons that we are lost in education today (Pinar, 2019) is that our education has become big business, and our schools have become far from Dewey's experimental school—a school in which competition and individualism had been given a place to collaborate. Dewey's plan focusses on both the social and intellectual aspects of education, cooperation, and collaboration in a form of community (Dewey, 1929, 1916; Tanner, 1991).

2.3. Joseph Schwab

After 60 years, we are at a time when Joseph J. Schwab recognized that the curriculum is "moribund," and it is "ripe for new directions" (Schwab, 1969). The 2020s, like the 1960s, are the time that history is being repeated. And it is the right time for *transformation* and "new directions for the curriculum," which is happening automatically and quickly with the technology of the Fourth Industrial Revolution during the pandemic. Schwab's "call for an emphasis on deliberation" and on the "practical for sustained improvement of the schools" (Flinders & Thornton, 2017, p. 119) best fits and reflects my approach and perspective in education towards a more sustainable future.

As stated by Joseph Schwab (1969) in *The Practical: A Language for Curriculum*, there is a need to divert the "bulk of curriculum" from "the theoretic to the practical, to the quasi-practical and to the eclectic" (Schwab, 1969, p. 103). Indeed, what does a theory cover and formulate? "A theory covers and formulates the regularities among the things and events it subsumes," according to Schwab (1969, p. 109). I strongly focus on a change in curriculum from theory to practice though "the stuff of theory is abstract or idealized representations of real things" (p. 110). I, moreover, emphasize a deliberative and positive collaborative learning environment where students can thrive with the use of updated technological pedagogical tools in their learning and education.

I would like to create an illustrative scientific metaphor here. If we carefully look at the issue of *heavy* curriculum (a curriculum full of content learning with various concepts and topics), we accept how it slows the student's progress and makes their learning harder. It seems that *heavy* curriculum does not let the student advance easily, and the student moves with some difficulty to the higher level. I, here, assume that you do not agree and accept this perspective. I utilize a concept in science and its scientific logic to convince you that *heavy* curriculum alone is not productive and effective with regards to the improvement in students' learning. However, this *heavy* curriculum can be truly constructive and progressive when it is accompanied with the right pedagogical thrust (upward force—an effective push for constructive progress) with "deliberation" in a positive collaborative learning environment. Therefore, I compare the *curriculum* to an *object* with a density in my metaphor and scientific discussion. We know that less dense objects always settle on top of more dense objects (Walker, 2002; Hawkes et al., 2014). In other words, the denser object stays at that lower level and cannot easily move (thrive) to higher levels because of its density, which is related to its mass and volume (Walker, 2002; Hawkes et al., 2014). For example, helium gas is less dense than the air; then it lifts and settles on top of the air (or can easily move upward), or wood, which we use for making boats that can float on top of water; whereas if we use iron or steel instead of wood, the object will sink quickly. Thus, the density of the curriculum matters when it comes to students progressing and thriving in their learning and education.

As mentioned before, the density is related to the mass and volume of the object (curriculum) (Walker, 2002; Hawkes et al., 2014). The mass of object—the amount of matter in an object—resembles the amount of content in a curriculum. Different objects with different masses look like different subjects with various curriculum content in education. The volume of the object—the measurement of the occupied space—is considered the same for the curriculum in education—a measurement of the occupied space by the required influential elements and factors in learning such as engagement, deliberation, collaboration, updated and useful technological and pedagogical tools, and so forth. According to the density equation, $\rho = \frac{m}{v}$, density equals mass over volume. As is clear in the formula, density and mass are directly proportional, whereas density and volume are inversely proportional. It means, by increasing the mass, density increases and vice versa. As such, by increasing the volume, the density decreases and vice versa. We see how science practically and beautifully associates with everything. Everything is science. Everything is and has a physics. Everything can be thoroughly related to physics. This is what we need and wish for young students to learn from physics and utilize in their everyday life, education and career. Physics can explicitly and implicitly support and develop our analyses of everything.

Let us advance it a bit. How and why does a cruise ship float on water and does not sink with its huge and massive size and mass? A cruise ship resembles the *heavy* *curriculum*. The reason that a cruise ship can easily float on water is buoyancy or because of a buoyant force (Walker, 2002; Hawkes et al., 2014). Buoyant force (thrust to thrive, achieve, and progress in learning) is an upward force exerted on an object (ship or curriculum) when placed in a fluid (in a positive collaborative and deliberative learning environment). The buoyant force (the upward force/thrust to thrive) has a direct relationship with fluid density (the extent of the deliberation and the positive collaborative learning environment accompanied with the right pedagogical tools) and fluid volume (the occupied space of deliberation, collaboration and use of updated technological pedagogical tools in learning) (Walker, 2002; Hawkes et al., 2014). When buoyant force (an upward force or the required thrust to thrive, such as motivation, engagement, encouragement, and so forth) is equal with the weight (downward force or the inhibitory factors in progressive learning such as discouragement, disengagement, reluctance, and so on) of the cruise ship (heavy curriculum) in water (deliberative and collaborative learning environment), the ship will not sink (the students will not fail to appreciate the essential value of the heavy curriculum). The only condition for sinking the ship is when the weight of the ship in water is more than the buoyant force, or the shape and design of the ship is not appropriate and efficient. The way that the cruise ship is designed and altered for better float and balance in water is similar to the way that the "bulk of curriculum" is diverted from theory to practice for experiencing a better, more balanced, and sustainable learning. In sum, when the heavy curriculum is not accompanied with updated technological pedagogical tools in a deliberative and positive collaborative learning environment, the student will not benefit from the planned curriculum and will not be able to easily progress and appreciate learning.

How much exhaustion is there in physics learning? How many failures are there in this practical subject? These are two-fold questions. I attempt to solve these frustrations and failures without any "flight from the subject of the field," as argued by Schwab (1969), to avoid any more crises and abhorrence in the field of physics, but not with the public and private school systems, not with formal educational systems connected to state "since what schools teach is a political as well as an educational decision, intertwined with issues of choice or standardization are questions of power, as George S. Counts had so well understood" (Flinders & Thornton, 2017, p. 120). Moreover, bringing changes and reforms to public educational institutions and K-12 schools is not an easy task (OECD, 2010b). It is complicated and impossible for various reasons which are not the focus of my study.

Schwab (1969), in “The Practical: A Language for Curriculum,” argues that “a large bulk of curriculum energies must be diverted from theoretic, not only to the eclectic but to the practical and the quasi-practical” (Schwab, 1969, p. 110). For example, Science Circles’ curriculum (a curriculum that I designed for an extracurricular and enrichment after-school science program in BC) constitutes both the theoretic and practical; however, most of the theory is converted to the *practical* or *quasi-practical*. This program attempts to regard and consider the eclectic aspect of curriculum too. Students integrate learning by connecting theory to practice in their everyday lives. Recorded demonstrations (videos), simulations, real experiments, and real demonstrations carefully selected from various topics and resources help them relate the theoretical concepts of physics to their applications while they are free to choose the activities, practices, problems, experiments, and even assignments.

The science program is comprised of three levels. Level 1 participants (6^{th} and 7^{th} graders) are students who mainly focus on learning mechanics and astronomy, which I believe supports their preparation and readiness for a much more developed and focussed physics curriculum. Level 2 participants (8^{th} and 9^{th} graders) and Level 3 participants (8^{th}, 9^{th}, 10^{th} graders) are adolescents who particularly focus their learning on an aimed and designed specific curriculum towards quantum mechanics, which I call *Wave-Quantum-Curriculum*. Level 2 students initiate their physics learning with basic principles and concepts of waves in classical physics and develop their learning to modern physics, quantum mechanics, in Level 3.

I strongly believe that Science Circles Program (SCP) attempts to demonstrate the contributions an extracurricular afterschool program makes to the students’ interest, engagement, and participation in the subject of physics as well as their understanding of how their everyday lives connect to the science of physics. What matters here is “how curriculum changes occur or how changes can be managed” (Schwab 1969, p. 106). The frequency of the students’ absences in the physics classes is an issue in STEM. Coping with the problem of what to teach, when and how in physics subjects for the aim of improving students’ interests and preferences for learning physics matters in redesigning the curriculum. This is what has been effectively and carefully considered in SCP's curriculum.

Furthermore, our practice of testing students has been transformed drastically as "one of the most interesting and visible alterations of present practice … is a radical change in our pattern of testing students" and evaluating their learning (Schwab, 1969, p. 113). The students' physics learning will be tested and assessed differently as our pattern of testing pupils has been significantly updated and changed by utilizing videos. There is no comprehensive exam or formal test. Students are encouraged to demonstrate their learning by their critical thinking (higher-order thinking) (Bonney & Sternberg, 2016; Halpern, 2007; Grant, 1988; Lipman, 1995), creativity, collaboration, problem solving (Bonney & Sternberg, 2016), and innovation skills during the program, which are mostly recorded throughout the program in various ways either by the students themselves or by the school. They enthusiastically record their understandings and practical experiences by producing videos of any theoretical concept they can bring to their application. They visualize, demonstrate, practise, "modify the theory in the course of its application," and take account "of the many aspects of the real thing which the theory does not take into account"; these are the arts of the practical emphasized by Schwab (1969, p. 110). Schwab argues that "curriculum is brought to bear not on ideal or abstract representatives but on the real thing" (p. 110). Moreover, in action and practice (the practical), complexities, failures, inadequacies, and deficiencies are determined and evidenced in the products of the curriculum. In other words, the practical is a way to diagnose the curriculum ills and would "call for a new and extensive pattern of enquiry" in curriculum "to seek its problems where its problems lie" (Schwab, 1969, p. 113).

Schwab (1969) points out that possible problems of curriculum proposed from many resources and "their possible importance debated from many points of view" are traced and found in forums where there is "the stage for display of anticipatory solutions to problems from a similar variety of sources" (p. 116). Though Schwab emphasized the importance of forums in 1969, we still do not see very active ones in the field of education. In a forum, learnings, new approaches, discoveries, gaps, and issues can be shared via dialogues and other possible ways amongst learners, researchers, and educators. For example, if I refer to the World Economic Forum, globally and nationally contemporary updated issues in various fields and topics will be explored and reflected there in which experts' and scholars' findings and perspectives have been shared. This is one of the reasons that I frequently refer to the World Economic Forum, as the most updated emerging issues from different topic areas and even geographies are being shared, and also recent publications can be accessed which support us in detecting, learning, and planning about the issues and developments ahead (World Economic Forum, 2021a).

2.4. Ralph Tyler

> *Contemporary life is so complex and because life is continually changing, it is very necessary to focus educational efforts upon the critical aspects of this complex life and upon those aspects that are of importance today so that we do not waste the time of students in learning things that were important fifty years ago but no longer have significance at the same time that we are neglecting areas of life that are now important and for which the schools provide no preparation.*
>
> *(Tyler, 1949, p. 54)*

According to Ralph Tyler (1949), four fundamental questions "must be answered in developing any curriculum and plan of instruction" (p. 51). As an example, I refer to my own lived experiences of writing and designing a science curriculum and lesson plans particularly focussed on physics concepts and principles in a science program, SCP, right at the beginning of the COVID-19 pandemic in March 2020. From my own point of view, I attempt to not only examine problems of curriculum and instruction but to also answer Tyler's four questions in developing the curriculum and plan of instruction on the subject of physics at the SCP for students in Grades 8–9, for instance. Tyler's critical questions with regards to developing any curriculum and plan of instruction are as follows:

1- What educational purposes should the [program] seek to attain?
2- What educational experiences can be provided that are likely to attain these purposes?
3- How can these educational experiences be effectively organized?
4- How can we determine whether these purposes are being attained?

(Tyler, 1949, p. 51)

Though "many educational programs do not have clearly defined purposes" (Tyler, 1949), my example, SCP, wisely and carefully aimed at and selected strong and well-defined objectives accorded with a comprehensive philosophy of education. Useful information and knowledge were provided in the process of investigating and selecting the objectives between the *essentialists and progressives* of the school—program directors, instructors, and a coordinator: one director (science director) and instructor as an expert in both fields of education and physics; the other director (actually co-founder, mathematics director, and general director of the school) and instructor as a subject specialist in both fields of mathematics and education; and the coordinator as an expert in the field of engineering. I, as a progressive and pragmatic optimist, emphasized physics content as well as students' interests, perspectives, and purposes as a rationale for their intellectually active participation and engagement towards learning since enhancing students' engagement is one of the aims of the curriculum as stated by Hargreaves (2005). On the other hand, the general director specialized in education and arithmetic, with the coordinator as the essentialists and progressives, from my point of view, considered and focussed on the main body of essential knowledge in science and utilized it as a key source for deriving objectives. It is significant that "The essentialist views objectives as essentially the basic learnings selected from the … past" (Tyler, 1949, p. 52). These objectives are not only concrete educational objectives focussed on content learning but also consider the students' outlooks.

We—directors, instructors and coordinators—should be able to determine "the basic information from which objectives can be derived" (Tyler, 1949, p. 52). Since "the school is viewed as the agency for helping young people to deal effectively with the critical problems of contemporary life" (p. 52), we were truly cautious and aware that we should be concerned with the contemporary problems in the students' lives and society, such as school closures, the global pandemic and the COVID-19 crisis, missing in-person and face-to-face classes and the opportunities of group work, hands-on activities in a real classroom, and so forth. Therefore, by determining these contemporary problems, we could know and aim for the objectives of the SCP, which is providing "those knowledges, skills, attitudes, and the like that will help … [students] to deal intelligently with these contemporary problems" (p. 53). Moreover, Tyler (1949) argues that each source of information has certain values and respectively should be briefly considered "in planning any comprehensive curriculum program," in obtaining useful information, and in recognizing significant educational objectives. In short, the program's objectives, with the help of various sources of information, were overtly determined by the members.

Indeed, “Education is a process of changing the behavior [including thinking, feeling, and acting] patterns of people” (Tyler, 1949, p. 53). As such, educational objectives are the changes in the students’ ways of thinking, feeling, seeing, and acting which are all brought to them by the educational institution and their programs. Therefore, a study of the learners themselves matters here, and is counted “as a source of educational objectives” (p. 53). An observation of students who participated in SCP may reveal the students’ difficulties and issues related to not only the students’ physics learning and interest in STEM education but also the physics curriculum and plans for instruction. These facts may suggest objectives in science education, particularly physics, in which girls and women are truly underrepresented. Observations of youths during the learning challenges and their struggles in the program may recommend objectives which would be achieved by redesigning and updating the curriculum, transforming the educational learning resources, and pragmatically connecting all of the scientific knowledge, skills, and information to students’ everyday lives and activities. By studying the learners and comparing the information about them with some desirable and acceptable standards, the disparities, gaps, and subsequently needs can be recognized (Tyler, 1949). A study of such gaps in Science Circles would help students to meet the required needs more effectively and gain motivation not only in the science program but also in their future career path in STEM.

Students need to be provided with opportunities to develop skills and knowledge in STEM and particularly in the subject of physics. However, there are some barriers and issues which would decrease the level of their interests in physics learning and preferences in selecting this subject of science. These would include students’ learning environment experience with teachers’ diverse approaches in teaching physics curriculum and its complexity, source of information, the time of learning—when learning physics is initiated, when students are introduced to this subject, and how long students would have the time and opportunity to become familiar with the principles and concepts of this discipline in K-12 education—and the pertinency of student learning and time.

Ralph Tyler’s standpoint about “studies of contemporary life” and “objectives,” besides the COVID-19 crisis, provoked me to consider the “contemporary life outside the school” and the ways students are challenged and struggle with the current status quo. It is essential that the student is not viewed as a failure in physics. Our work is to encourage and keep the passionate and motivated students driven in this field. We teachers try to help them to find their purpose. The majority of students feel disappointed and fail to appreciate learning content and the intrinsic value of the curriculum content in their education (Pugh & Phillips, 2011; Emdin, 2016). However, they are not failures because they try something that seems complex and *hard*, and it does not work out. Students fail only when they stop trying to get back on the right track of learning. Administrators, educators, and teachers with the educational curricula at the educational institutions would never want students to view their efforts as a failure. No one would ever like to view themselves as a failure. The key point is in *change*. We—both students and teachers—can alter outlooks, interests and preferences by changing the attitudes of not only ourselves (our pedagogical approaches, the curriculum, and the expected learning goals) but also the students' attitudes. This is a kind of *transformation* that can be deliberately applied in education. The reason for this *change* pertains to contemporary life.

It is noteworthy that "the advent of science and the Industrial Revolution" significantly developed the body of knowledge (Tyler, 1949). However, what knowledge is most worth learning in science education in the 21st century? It is substantial that we need to create sustainable, resilient, equitable learning environments, spaces, and places for 21st-century students. All these factors would not be fulfilled without transformation and reform—a shift towards intellectualization. For the aim of having a more equitable learning environment, first we consider the gaps that exist in the field of physics—girls and women being unrepresented and physics as an abandoned subject.

Moreover, we need to recolour the outdoors for our content learning in physics. We ought to transfer the in-person classrooms to a hybrid approach and a combination of outdoor, nature, real life, community, and virtual/online/remote settings. For the purpose of connecting physics content and curriculum to the students' everyday lives and situations, we should refer to where students' lived experiences and learning take place. It means that similarity between the life experience and the learning situations—the similarity between content and context of students' everyday life—can obviously help identifying learning objectives and easing the process of learning. Therefore, creating a curriculum and instruction plan that embraces the students' perspectives, studies of contemporary life, views of their contemporary life, and contemporary desirable activities may significantly increase their engagement and interest of learning.

Indeed, our contemporary life has been strongly interwoven with technology and digital devices, and COVID-19 has tightened this connection and dependency more than before. For example, light-based quantum technologies, “optical telecommunications and sensors are well-established technologies that we use every day” (Walmsley, 2015, p. 527). Is learning about these influential everyday experiences and technologies worth it in science education? In the process of connecting contemporary life and curriculum, it is necessary to take care of the contemporary aspects, factors, and matters that not only would develop contemporary knowledge and skills to prepare students to solve the current problems today but would also enable students to solve them in the future too. These problems and concerns unprecedentedly will change due to the Fourth Industrial Revolution.

“What can this subject contribute to the education of young people who are not to specialize in it?” (Tyler, 1949). Physics, particularly modern physics, can make great contributions to a wide range of young students who are not even interested in the field of mathematical and physical science. In the realm of science, I saw different kinds of contributions in terms of the major functions physics can serve. During the preparation of the Science Circles’ curriculum, I was constantly asking myself: *How can my physics curriculum contribute to the education of adolescents in the 21st century and to the future of their lives and careers for those who are not going to be a specialist in the field of physics*? The students should be provided with opportunities to be able to see what this subject can do for them in the future and its use outside its field and in their everyday lives. Once again, in all aspects, students’ points of view and interests must be adequately considered in curriculum and our pedagogy.

To conclude, with the Science Circles’ curriculum, I reveal how the students in grades 8 and 9 can develop a clear understanding of the basic principles and concepts of quantum physics and light phenomena. “Light facilitates exploration of quantum phenomena that illuminate the basic properties of nature and also enables radical new technologies based on these phenomena” (Walmsley, 2015, p. 525). The physicist Richard Feynman states that “Nature isn’t classical …, and if you want to make a simulation of Nature, you’d better make it quantum mechanical” (Feynman, 1982, p. 486). There are problems in science that scientists have failed to solve with classical physics and digital computers like quantum physics problems that could be easily solved with quantum computers (Preskill, 2018). This is where our *young scientist*s can think of the use of quantum physics for the future (He et al., 2021; Venegas-Gomez, 2020; Akdemir et al., 2021; Franklin et al., 2020a, 2020b; Krijtenburg-Lewerissa, 2017). The SCP demonstrates how a focussed curriculum (*wave-quantum-curriculum)* on one scientific knowledge and a big idea can develop an advanced understanding of complicated concepts like quantum in the lower grades of 8 and 9. In short, students' engagement, their learning outcomes, and interests in learning physics will reveal the extent to which the SCP's objectives have been successfully attained.

2.5. William Pinar

William Pinar planned and developed the method of currere—the "infinitive form of curriculum means to run the course"— "to support the systematic study of self-reflexivity within the processes of education" (Pinar, 2004, p. 35). This educational method is "a strategy for students of curriculum to study the relations between academic knowledge and life history in the interest of self-understanding and social reconstruction" (Pinar, 2004, p. 35). It means, from my point of view, that one returns to the self and the lived experiences—the roots of and reasons for acquired knowledge and consciousness—attempts to remember, review, understand, connect, analyze, detect (not only the issues, gaps, and lacks but also the strengths, accomplishments, and successes), synthesize for various objectives, imagine the future, conclude in the present, save wherever is possible, apply whenever is needed, and finally again utilize in the present, which is one day the future (before). Today is the tomorrow that we were worried about, thought about, and envisioned yesterday. Then, the present is and should be the moment of the act and turn. The moment of change. Pinar's method of currere comprises four steps—the regressive, the progressive, the analytical, and the synthetical—which emphasize "both temporal and cognitive movements in the autobiographical study of educational experience" (Pinar, 2004, p. 35). In short, currere brings a possibility of "self-reflexivity" and "self-realization" as well as "self-affirmation" (Pinar, 2019, 2004).

According to Pinar's devised autobiographical method, "returning to the past (the "regressive") and imagining the future (the "progressive") must be understood (the "analytic") for the self to become "expanded," and complicated, then, finally, "mobilized" (Pinar, 2012, p. 5). Therefore, I will refer to my lived experiences—lacks, gaps, issues, deficiencies, opportunities, and successes—in the past as "we teachers must remember the past and imagine the future, however unpleasant each domain may be" (Pinar, 2004, p. 4). Pinar asserts that we must intellectually and characteristically experience temporality while "living simultaneously in the past, present, and future." (Pinar, 2019, 2004, p. 4). I, as a teacher and educator, review the past of students' physics learning (including myself) while acting in the present by reconstructing that path in a science program and envisioning the future for students who will become young physicists of their own families/communities and become able to learn even complicated topics such as quantum physics at an early age (grades 8 and 9). I move a lens over my own lived experiences, attempt to shed light on the issues as well as causes and resonate with some incidents with regards to participation, preferences, and interests in the field of physics.

I also echo this question: What is the aftermath of having an abandoned subject in science, having either vacant physics classrooms or only one or two students? I have been and have taught in such a classroom. From this "regressive moment" …"reactivating the past in the present—I move to the progressive moment, in which we focus on futuristic conceptions of education as exclusively technological" (Pinar, 2019, p. 8). This understanding and consciousness "can help us to understand our situation" (Pinar, 2019, p. 5) as a huge shift and a desire for revolution seem to be happening (Schwab, 2016); the crisis of COVID-19 is reshaping everything, especially education and our educational classroom, environment, and place (Schleicher, 2020; Reimers & Schleicher, 2020). Technology and digital objects are becoming one of the important parts of our body, frequently being attached and detached from the body. Very soon, digital objects such as smart dust, smart pills, and digital tattoos will be more connected to our bodies, wearable and implantable (Arnault, 2014). These implanted objects will be able to read brainwaves as well as other signals and also recognize potentially unexpressed thoughts or moods (Schwab, 2016).

Technology and our minds, which are frequently hovering over the past, the present, and the future, are genuinely collaborating. It seems that we must become accustomed and habituated to the technology, as claimed by Adams & Thompson (2016). From Pinar's views, "The computer becomes the latest technological fantasy of educational utopia, a fantasy of 'teacher-proof' curriculum, the fantasy of going where 'no man has gone before'" (Pinar, 2004, p. 8; 2012; 2019). This is something that involves and targets the in-person presence and connections of human beings everywhere on Earth. This is what we all have recently experienced in the world. This is something that has changed, continues to change, and will change so many things and the definitions of them—the definition of connection, definition of present, definition of absent, definition of *place*, definition of *environment*, definition of space, definition of *time*, and eventually definition of reality. This is the so-called Fourth Industrial Revolution and *time* is the most important thing here.

After considering the future in the present during the "progressive moment," I turn to the moment of reflection and self-understanding, the first analytic moment of currere. The moment in which we detect "anti-intellectual conditions" and "anti-intellectualism" as "the field of education has (understandably) remained underdeveloped intellectually," claimed by Pinar (2004, p. 9; 2012; 2019). "The exchange and acquisition of information is not education. Being informed is not equivalent to erudition. Information must be tempered with intellectual judgment, critical thinking, ethics, and self-reflexivity" (Pinar, 2004, p. 8). Indeed, what is counted as knowledge and education where the information is being either easily accessed or noticeably traded? What are the impacts and consequences of the information without intellectual, critical, and ethical factors and principles? Karen Barad (2007) elaborates on the ethical ways of knowing and ways of being in her agential realism theory—a new integration of epistemology, ontology, and ethics in science. Moreover, Sir Ronald Cohen (2020), in his recent book *Impact*, argues that education has been, is, and will be an investment and asset for people. I completely agree that erudition is an asset and worthy investment since education has been accompanied with learning and knowledge. However, is this tradable? Is real education—learning/erudition—a business? From Pinar's standpoint, education is not a business though business needs education and skills—a diversion of theoretical to practical.

Pinar (2019), in "What Is Curriculum Theory?" explicitly offers his feasible solutions to decrease the "anti-intellectual conditions." Pinar (2019) decisively affirms that "self-criticism" and "complicated conversation" with ourselves, our students, and our academic subjects will keep us away from "anti-intellectualism" that is deep-seated and prevalent in the field of education (Pinar, 2019). This complicated conversation will occur with "intellectual freedom" to create the curriculum we teach, the pedagogical approaches we utilize to teach and assess students' learning (Pinar, 2019). We as teachers and educators may need to overcome the anti-intellectual barriers; thus, the aim is to continue the project of “intellectualization,” as emphasized by Pinar (2019), if we really are a teacher in a school, not a technician in a factory of skills and knowledge. We must facilitate intellectual conditions. Consequently, we—teachers, parents, educators, administrators, politicians—will be able to individually and professionally “mobilize” ourselves (Pinar, 2019) to act. We need to remember “what is at stake in the education of children, an education in which creativity and individuality, not test-taking skills, are primary” (Pinar, 2004, p. 10). I am wondering where our academic and intellectual freedom is. I am wondering whether the students are being indoctrinated and “forced to learn what the test-makers declare to be important” in education, as emphasized by Pinar (2019, p.10). Is there any business in test-making?

I am using the autobiographical approach because “such an autobiographical sequence of ourselves as individuals and as educators might enable us to awaken from the nightmare we are living in the present” (Pinar, 2004, p. 5); the nightmare of miseducation, underrepresentation, and indoctrination. These are the things that I have experienced in the past and experience in the present. I confidently refer to Pinar's autobiographical method of *currere*, “the infinite form of curriculum,” a method focussed on “self-understanding,” “self-realization,” “self-reflexivity,” “self-affirmation,” “self-mobilization,” “intellectuality,” “interdisciplinarity,” and “erudition.” With the aim of having a place in education for “creativity, erudition, and interdisciplinary intellectuality” (Pinar, 2012, p.11), I deliberately and consciously return to my past experiences, imagine the future of education and professions, analyze and mobilize myself, and reconstruct a curriculum and pedagogy in the present. I pragmatically act in the present and adapt myself to make better progress towards a more sustainable future. To sum up, this autobiographical method, in fact, asks us to slow down, to remember, to even re-enter the past, and to meditatively imagine the future (Pinar, 2019, p. 4).

Chapter 3.

Need for Reform During the Fourth Industrial Revolution

3.1. Changes

3.1.1. Real Reality

I return to one of my mathematics classes at the Simon Fraser University's beautifully constructed and developed Surrey Campus in the last safe and pre-pandemic school year—the regressive moment of *currere*. It is my first experience of officially teaching at an educational institution like SFU. I am neither teaching nor working as an SFU employee; I am working for an independent enrichment after-school program in Vancouver, BC, at their SFU Surrey Campus.

On a gorgeous Sunday morning, the sunlight peeks though the clouds turning and dancing in the sky. On such a day, many people would be spending their time by the beach basking in the glory of the sun or walking beside the water; however, I vigorously devote my day to my passion of teaching and sharing my knowledge to passionate learners and knowledge seekers. I walk into an architectural masterpiece. I am welcomed by a grand hall, with a roof so high you could truly see how vast this establishment is. Heading down the walkway, I notice the embellishment of beautiful carpeting that adds a hint of comfort to an otherwise serious educational *environment*. I step into a modest yet modern classroom equipped with everything necessary to provide a strong and welcoming learning *environment* for students. I always arrive at my classes 15 to 30 minutes ahead of time to set up the class *environment* for my students' learning and to make ready to utilize the prepared materials, such as printed worksheets and handouts. I am immersed in peace and quiet.

The classroom has been equipped with blank canvases waiting to be decorated with the majestic art of knowledge. Rows of tables consisting of smaller tables and comfortable cushioned chairs with rolling wheels will welcome enthusiastic learners. SFU classes on the second floor at the Surrey campus have been equipped with six white boards attached to the walls around the students' seating area. Two large white boards are at the front and two on the left and right sides of the classroom. Minerals mined from the beautiful earth conjoined into one technologically advanced masterpiece provide endless opportunities for communication, literacy, and the realization of inner potentials and passion. There is a well-designed table with a brand-new computer on it and a projector with curtains that cover the two large whiteboards at the front. This acts as a theatre scene for knowledge, giving life to imaginations, innovations, and dreams while also providing new opportunities for unique creations. It is a comforting *space* providing an educator with room and *place* to focus on teaching and educating the future generations while being equipped with the newest and finest educational technological tools. The computer has a strong internet access, with required software and platforms for teaching and learning.

The entrance door of this well-designed learning *environment* is at the back-right side when you stand in front of the class facing the learners. Next to the door, there is a full-length window with the same proportions, providing a sense of comfort and relief to parents and guardians, with a crystal-clear lens that allows onlookers a first-hand experience of the art of mathematics. When the students enter the classroom, they can easily pass through the seating area and come to the front of the class or turn to the right and go around to the other side of the class.

Indeed, "*place* and human feelings are intertwined," as argued by Pinar et al. (1995, p. 533). I believe that teaching high-school-level mathematics in such an educational *environment* and *place* creates for the instructor a unique and thrilling experience of working and living with students. However, this is not the main point and lesson to be drawn from this unprecedented teaching opportunity and situation. There are lots of opportunities and significant factors associated with students' learning and achievement in such an educational *environment* and *place*, specifically for high schoolers and adolescents. "Place [is considered] as an important concept for understanding curriculum," as claimed by Wang (2020, p. 4).

Since the COVID-19 pandemic, we have been experiencing a huge shift towards technology, the digital environment, and an online connection, interaction, and collaboration though ongoing research is being done on the impact of COVID-19 on education. "Dewey claimed that educational research could and should combine both the experimental and the natural" (Shulman, 1997, p. 19) and "a laboratory school's special function was to create new standards and ideals and thus to lead to a gradual change in conditions" (Lagemann, 1988, p. 197). It seems new standards and ideals are needed beside gradual change in conditions with the COVID-19 crisis. The real classrooms are being transferred to virtual Zoom classrooms. A vast movement seems to be happening, and the crisis of COVID-19 is reshaping everything, especially education and our educational classrooms, *environment*, and *place*. With schooling disrupted (OECD, 2020a), students' learning *place* and *space* is no longer like the illustrated building and classrooms at the SFU Surrey Campus. Only a name of an educational institution has been left for students and teachers as a *place* of education.

In brief, traditional schooling systems have broken down, and schooling rethought (OECD, 2020a). At issue here is missing in-person activities in real places and spaces. At issue is whether virtual teaching and the learning *environment*, *space,* and *place* like Zoom and Team classes are sufficient not only for students learning but also for teachers teaching. The goal of this section is to illustrate and focus on the recent changes in education (due to the current status quo and crisis of COVID-19) and our ways of learning, and how to improve and adapt ourselves to make better progress towards a more sustainable future. Furthermore, I highlight the reasons that brought me to this view; there is a need to recreate and reform our pedagogical approaches and teaching techniques and styles with the aim of increasing the efficiency of virtual teaching and learning, primarily in Canada, the US, and elsewhere. We must learn from the COVID-19 crisis. We need to consider and understand *how COVID-19 has impacted education and the students' learning environments and places.*

3.1.2. Short Orientation

Only recently have our education, work, and lives in the 21st century truly and strongly been interwoven with technologies. Don Ihde (1990), a post phenomenologist, states that "the form of instruments and devices by which we make 'worlds' available to us which were previously unexperienced and unperceived. Instruments are the means by which unspoken things 'speak,' and unseen things become 'visible'" (p. 20). Digital devices, technological instruments and sensors are now everywhere; they are closer to us than we think—cellphones in our hands, digital and wireless headphones in our ears, and digital watches on our wrists. Moreover, by 2025, the first implantable mobile phone will be commercially available to us (Schwab, 2016). This is not the only digital object that is becoming connected to our *bodies*. There will be more wearable and implantable digital objects available to us in the future, such as digital tattoos, smart dusts, smart pills and medical objects (Arnault, 2014). We form a unity with digital devices and technological instruments; they become part of our *bodies*. In fact, it is a time-consuming process, and it forms gradually as time and practice are needed for the *body* to adapt and change (Adams & Thompson, 2016; Van Lennep, 1987).

Our work and education, even our daily activities have been digitized, and a huge amount of data from human activities and inactivities are being stored and again saved in huge digital devices. It is like a closed loop. These data are being processed, analyzed, and again utilized to enhance our lives in the 21st century. “Microsensors track and digitize human activities, algorithms manipulate the data generated, then feed us steady streams of information about ourselves and the world around us” (Adams & Thompson, 2016, p. 1). Ultimately, technology and digital objects are becoming one of the important parts of our *body* by frequently being attached and detached from the *body*. It seems that we must become accustomed and habituated to the technology, as claimed by Adams & Thompson.

3.1.3. Turning Point

Indeed, we ponder how fast it is happening. All around the world, we are experiencing a high-paced revolution and shift towards digitalization and technology. We ponder how and when the pace changed, and when the turn happened. We ponder the cause of this sudden change. It is now more than twenty-four months that the world has been dealing with a pandemic, COVID-19—since March 2020. This is a crisis and a health threat for everyone on Earth. This is something that involves and targets the *in-person presence* and *connections* of human beings everywhere on Earth. This is something that changes the definitions of so many things: *connection*, *present*, *absent*, *place*, *environment*, *space*, *time*, and eventually the definition of *reality*. I ponder and wonder that, with the current world-wide changes, the definitions are being totally changed or not, or just some elements and aspects are being added to the previous definitions. This might be a form of *refiguration* and “the kinds of shifts in refiguring space, time, and matter” as Barad (2007) argues in her book, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (p. 224). She explicitly claims relations of space-time-matter and argues how these relationships shed light on “the need for an ethics of responsibility and accountability not only for what we know, how we know, and what we do but, in part, for what exists” (Barad, 2007, p. 243). Definitions and relations are being reconfigured or reformed as technology brings us so many new delineations and meanings which must be properly added to the previous ones. In fact, definitions are being updated and modernized with technology due to digitalization and creation of new digital avenues and streams.

3.1.4. Reset Button

The COVID-19 pandemic and crisis paused the world and closed everything that was related to human beings’ presence: *places*, like stores, companies, factories, offices, institutions, schools, and classes. According to the OECD, school closures across the OECD countries for an average of 14 weeks locked 1.5 billion students and their parents out of their schools. Below, Figure 3.1 with different colours for localized and nationwide, illustrates the number of OECD and non-OECD countries with school closures due to COVID-19 since February 2020.

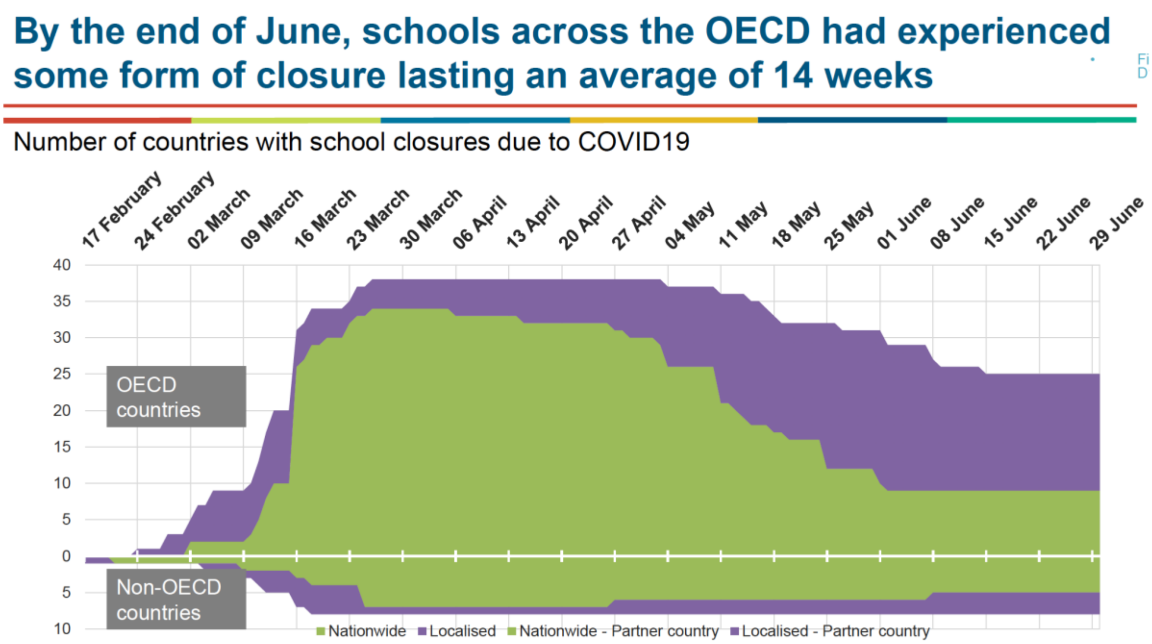


Figure 3.1 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

As schools closed around the world during the first difficult wave of the pandemic, the educational institutions and ministries of education rapidly developed and deployed various projects and approaches to reach primary, secondary, and post-secondary students to help them continue learning. Not only did students need to be provided with educational materials and remote lessons, teachers and instructors also needed to connect with their students. Some approaches suggested making the lessons and materials available online to students to maximize the reach (Figure 3.2). Therefore, they initiated using different online platforms and many highly innovative learning environments emerged, such as Microsoft Teams for content learning and Zoom for connecting and virtually becoming *present* to the students. In short, remote and online learning became the best solution in education (Figure 3.2).

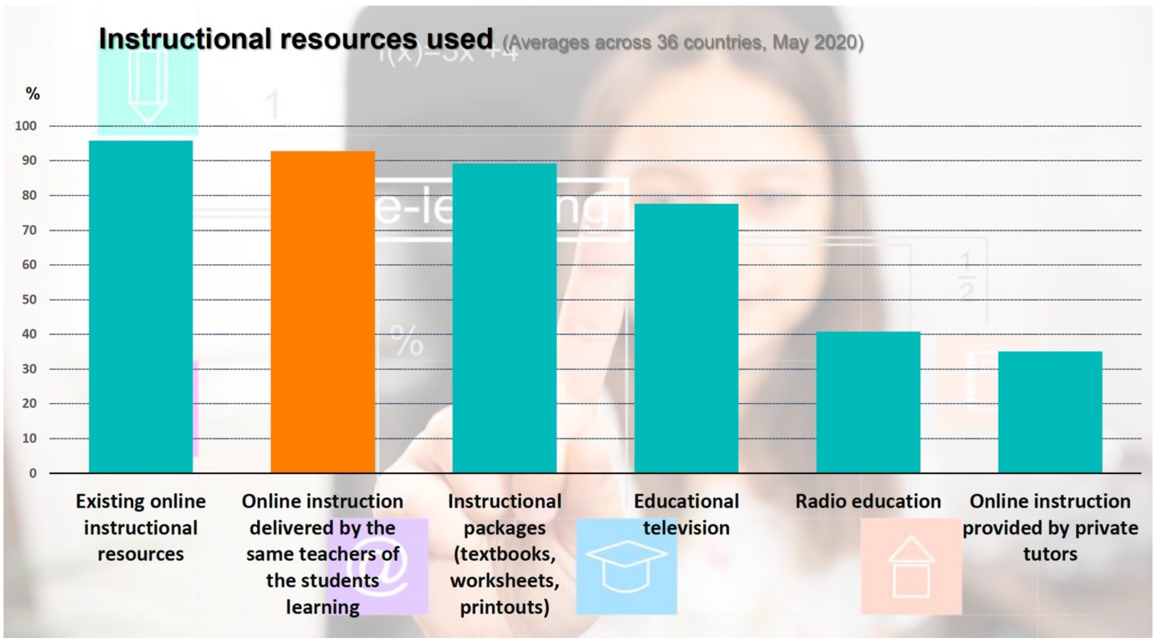


Figure 3.2 Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?

The educational institutions and ministries had to observe and investigate how teaching and learning could take place during the school closures and create a report and overview of how the systems were being adapted during the crisis. Each country was responsible for finding solutions which would work for their own contexts though they could also learn from one another and see how other countries could adapt their learning systems. However, after all these challenges and ups and downs during the pandemic, now most of the educational systems prefer an online working, teaching, and learning approach. The educational institutions acknowledge that technology can amplify and scale innovative teaching and faster ways of learning. Consequently, it demonstrates that a virus in the size of "50–200 nanometers in diameter" (Chen et al., 2020) could successfully work not only as a reset button in the world but also as a thrust towards digitalization, automation, mechanization, computerization, telecommunication, and cybernation in the world (Schwab & Malleret, 2020).

3.1.5. New Place and Space for Learning

The results of the OECD demonstrate that about 99% of students have internet access at *home* and 95% of students have a computer for their schoolwork at *home,* across the OECD countries and economies. In addition, more than 94% of students have a quiet place to study at *home*. Most of the students are experiencing online learning in their new learning environment, *at home* (Figure 3.3) though some will be disadvantaged in this process.

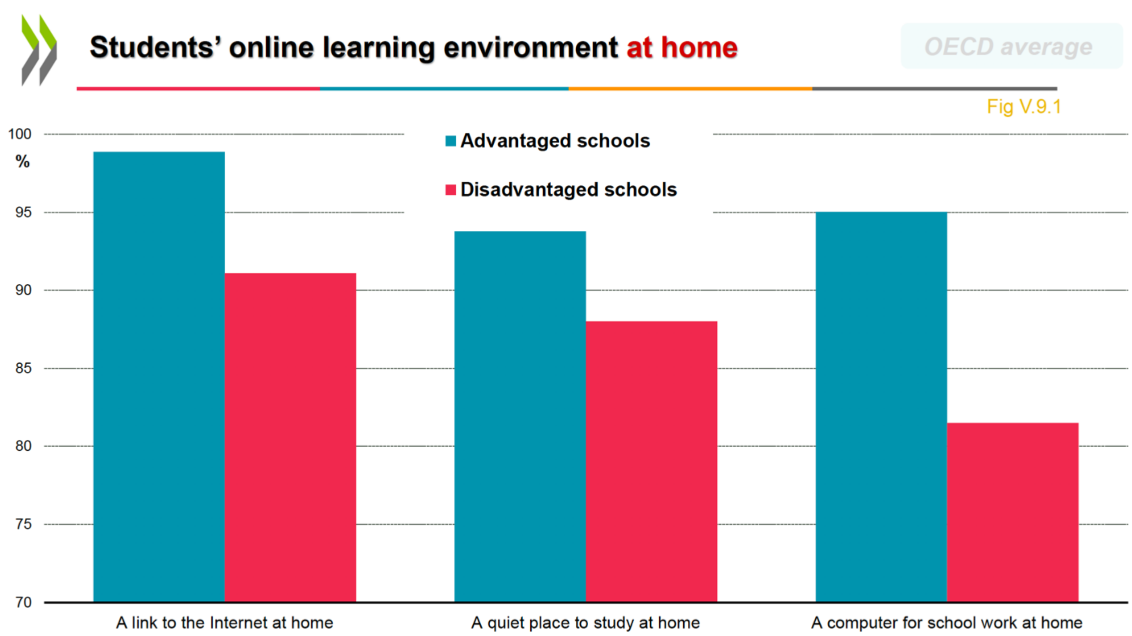


Figure 3.3 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

Moreover, in some countries, based on the principals' reports, schools were able to provide each student with a computer to study such as in Canada, United Kingdom, United States, New Zealand, Iceland, Australia, Austria, Singapore, and Norway (Figure 3.4).

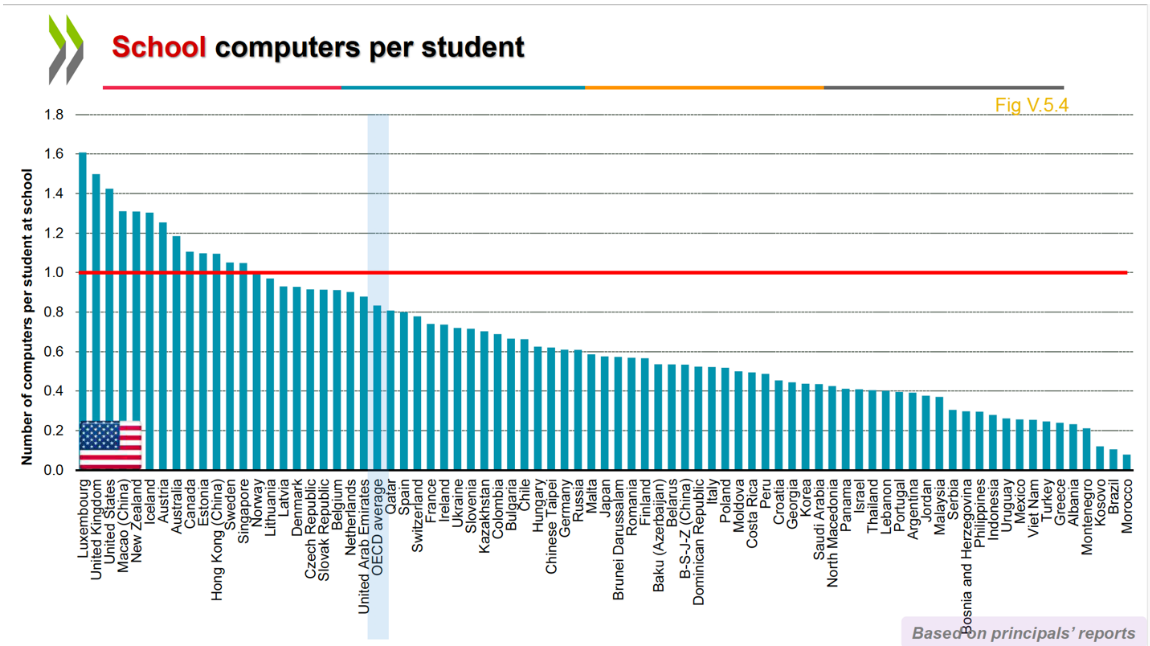


Figure 3.4 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

All these statistics and studies demonstrate that students, teachers, and parents are adapting and being updated with new online and distance learning and other innovative approaches in education. They effectively entered the new learning *place* and *space*—online/virtual and at home. Reopening of K-12 schools occurred when students' and teachers' "e-learning readiness" were confirmed (Figure 3.5). Close to 85% of teachers were targeted for training and professional development on effective e-learning and assessment (Reimers & Schleicher, 2020). Alternatives, such as radio and TV, were developed for students without internet access and network connection to approximately 68.5% across 36 OECD countries, and 79% invested in "updating or creating effective e-learning platforms and content" for students and teachers (Reimers & Schleicher, 2020).

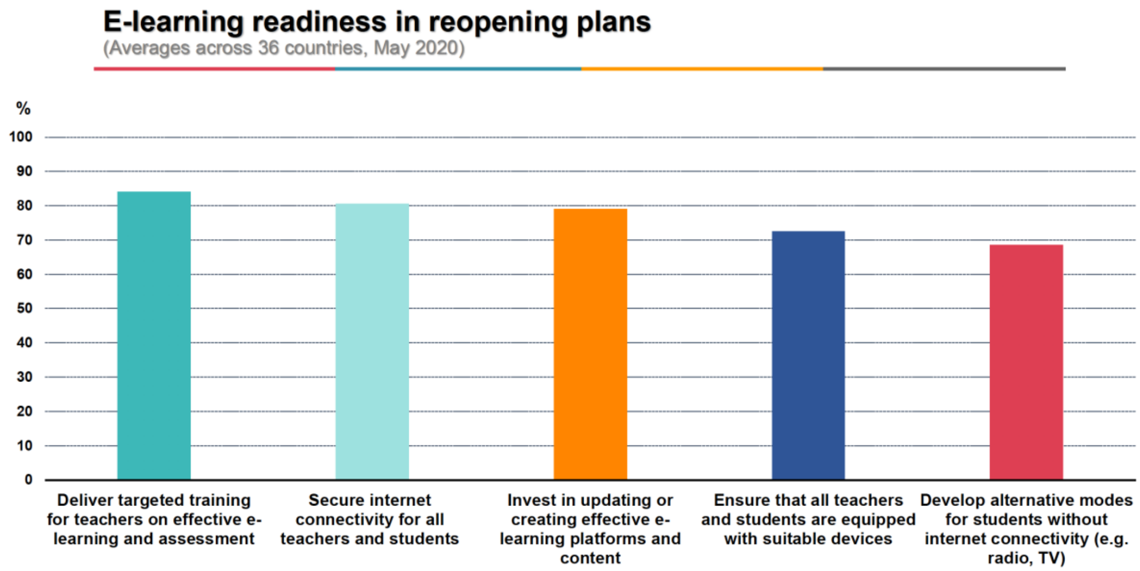


Figure 3.5 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

Students and teachers came out of the in-person classrooms (face to face) and mostly shifted to study online (virtual) in home environments. “Learning takes place through more diverse, privatized and flexible arrangements, with digital technology a key driver” (Schleicher, 2020). Instructional resources and class activities have subsequently changed. Simulations and videos have replaced in-person, hands-on activities of real classrooms. Now students have access to infinite information and training options. The nature of teaching and the role of teachers is changing (Luthra & Mackenzie, 2020). Teachers are becoming students’ collaborators and facilitators. Dewey (1916) stated that students as active participants and teachers as collaborators and facilitators should learn together in a democratic society. “Remote work and blended learning may drastically blur distinctions between home and school, time for study/work and time for leisure” (Schleicher, 2020). Therefore, learning either formally or informally can take place anytime and anywhere.

3.1.6. Stop and Let Transfer

The future will continue to surprise us. Even though the pandemic has caused tension and anxiety in our lives, it is creating new opportunities too; we need to stop, to take a pause. I refer “to the importance of Appelbaum’s (1995) concept of the *stop*, and how attending to those moments that tug on our sleeve as embodied data for pedagogical exploration can enlarge the space of the possible" (Sumara & Davis, 1997; Fels, 2012, p.51). This *stop* invites us to find and open a space for listening, perceiving, exploring, and finally turning to the ideas that will support us in the future.

The world may well have needed a *stop*. In a sense, COVID-19 with all its challenges, tensions, and impacts as a pandemic, has provided us with an opportunity to *stop*, to *pause*, to meditate, to review, to reset, to become able to start again for redesigning, reconstructing, and rebuilding a better future. For the sake of our well-being, we may well need to slow down. To enhance our quality of work and quality of education, we might not need to increase our speed as AIs (artificial intelligence) and robots will be taking care of pace, precision, and accuracy soon. It is the right time to transmit some of our responsibilities to AIs and robots; it is the time of the Fourth Industrial and Digital Revolution (Schwab, 2016). This is the century that scientists and researchers—human beings—have doggedly and overwhelmingly worked day and night to utilize intelligences, capabilities, knowledge, and powers like a machine and computer to create artificial intelligence and robots. As a global society, we may have come to a time to use and benefit from all the discoveries of the 21st century. However, we are not sure how long it will take and to what extent robots will be substituting for us in various sectors (Schwab, 2016, p. 38). What might be the significance of high-performing robots and AIs that perform with fewer errors and uncertainties?

A temporary *stop* might transfer the work and *place/space* of our work, such as coming out of the Surrey Campus classrooms and entering Zoom classes. Yes, in fact, the places in which knowledge can be granted to knowledge seekers and receivers have changed. From my point of view, in this impermanent *stop*, "a slow pedagogy" can be an approach to adapt and update as "a slow pedagogy […] allows us to pause or dwell in spaces for more than a fleeting moment and, therefore, encourages us to attach and receive meaning from that place" (Payne & Wattchow, 2009, p. 16). The *place* between SFU Surrey Campus and Zoom, in which innovation, creativity, architectural masterpiece, digital devices, technologies, potentiality, reality and virtuality all come together for the aim of creating high-quality education.

We human beings need to be ready to have new collaborators—robots (Schwab, 2016). We will, though, have new responsibilities and work which is not doable by AIs and robots (Schwab, 2016). Schwab claims that more flexible robots with complex biological structures, functions, and sensors will collaborate with humans. Robots are able to understand, respond to their environment and remotely access information via the cloud and network connection (Schwab, 2016, p. 21). Researchers reveal that robots are entirely able to collaborate with humans which is called human-machine collaboration. Humanoid robots are the tangible example of a technology that may substitute for faculties like instruction, meetings, and tutorials, by focussing on "critical thinking and creativity serving scholarship […] and instructional initiatives" (Elbeck, 2018, p. 117). However, AIs and robots do not have the creativity, innovation, and ability to think critically or come up with new ideas independently. They are better at speed and accuracy. They are better at receiving data and processing it but are not able to analyze, which is the expertise of human beings. Therefore, this is why being capable of thinking critically, solving problems, and being innovative and creative (Alos, 2018) are the required and even vital skills for us to succeed in the future of the 21st century.

3.1.7. Pandemic Over Pandemic

Before the COVID-19 crisis, the world had already been dealing with another pandemic. Bai and Cohen (2019) point to a "pandemic in our current civilization"—*existential lack*. They argue that the reason for this pandemic and the underlying point is embedded in *self*—a teacher and an educator [a student]. They believe that the source and reason for this *existential lack* could be examined in the "struggling experience of frustration, impatience, anger, helplessness, hopelessness, dejection, and giving up" (p. 22). These are all experiences that might also occur in the process of change. Change is a time-consuming process though it can happen at different speeds and directions. Bai and Cohen (2019) propose that we need to start from our *selves*, and the world will gradually follow. In other words, they recommend that change in our *selves* can be a solution which will result eventually in changing the world. According to them, "We change who we are, which changes how we act in the world; then, this will change how the world comes into shape and form" (Bai et al., 2014). For this change, learning is required. As claimed by Bai and Cohen:

> Learning requires change. There is no learning without change: for, learning always implies that the learner is seeing, feeling, thinking, and doing something new and anew, fresh and different from before. Otherwise, there is no learning: only conditioned seeing and behavior. Hence, learning and ma are intimately connected: to learn, one needs to enter ma. The

> more deeply one can inter ma, the more transformative will be one's learning. (Bai & Cohen, 2019, p. 19)

In other words, when learning is achieved, change is manifested. Therefore, change is also considered as a solution for this pandemic too.

Bai and Cohen (2019) propose a viewpoint that learning happens by introducing a term in education called ma, which “can be discovered, perceived, and seized upon, and action can take place that brings about desired changes” (p. 17). Ma is a space of possibilities for change and transformation, a gate that “provides some horizons beyond everyday consciousness,” an “art of attunement,” and finally an achievement (p. 17). Moreover, ma is related to time as it “represents dynamic change moment” (p. 18). In fact, attunement and flow are significant factors for entering into this space. In the experience of attunement, we attempt to change “transformative possibilities moment by moment” and become able to “work with unfolding possibilities” (p. 18). It is important that all are contingent on human perceptions.

As Bai and Cohen (2019) emphasize, learning needs complete openness, presence, participation and “being-with-ness, moment by moment.” In fact, living experience with flow and attunement is an achievement (Csikszentmihalyi, 1996; Wang, 2020). Besides, learning is having possibilities for change and transformation and vice versa. Therefore, learning without living experience and achieving is like having possibilities for change and transformation without having flow and ability for attunement. Being attuned, experiencing flow, and awaking human beings is required for learning (Wang, 2020). Working with ma is beyond critical thinking and problem-solving. It “requires complete integration and alignment of mind-body-heart-spirit” to have a degree of attuned consciousness (Bai & Cohen, 2019, p. 23).

Here, there is a question: How will learning by entering ma help students, teachers, and educators gain new skills for making real progress towards a more sustainable future? Not being open to learning and change leads to rigidity—frozen, closed-minded, dogmatic, and shut-down states of consciousness—fear, insecurity, inadequacy, doubt, shame, worry, anger which all will consequently result in resistance, hesitancy, defence, and presumably offence, as argued by Bai and Cohen (2019). It is significant that critical thinking (Bonney & Sternberg, 2016; Halpern, 2007) and problem-solving are required skills for being able to make real progress towards success and achievement (Schwab, 2021). Moreover, resilience, stress tolerance, and flexibility are likewise the skills which would be learned by entering ma for the aim of having a more sustainable future. As such, first, we need to start from self with “attuned relational humanity” practices that awaken human beings in the era of digitalization, mechanization, and manifestation of artificial intelligence. It is intriguing that “the chain of interconnectivity and interpenetration extends to the whole universe” (Bai & Cohen, 2019, p. 19) and interweaves everything in the world.

Furthermore, having resilience, stress tolarance, flexibility, and ability for attunement and flow will benefit us in our social, educational, and professional journeys of the 21st century. Human well-being matters here as a more digitally-connected world has created higher expectations which can cause significant consequences and risks when prosperity and access either are not attainable or occur with lower chance (Shewab, 2016). Besides, there is a reciprocal relationship between human well-beingness and being able to have creativity and innovation, having the abilities of analytical thinking and problem solving, and coming up with new ideas consequently. Therefore, those are the practical solutions which can be useful in protecting people from the impacts of psychological tensions and problems due to the past, current, and future challenges.

3.1.8. How to Adapt with Changes and Challenges to Maintain Our Well-being

To overcome the challenges and pressures, Bai (2013), in keeping with McGilchrist and other brain scientists, believes that we need to apply some changes “in what we value and find meaningful,” and find different ways to “spend our time and energy” with the aim of holding “an embodied and animated perception of the world” and our well-being. She asserts that contemplative practice—to calm and quiet the mind—is a different way towards an empathic world and living more “animated, bonded and belonging, loving, happier, and fulfilled lives.” Moreover, Smith (2018) deems that “life phenomenology attempts to realize the relationally affective, mutually-interactive and animatedly-inter-corporeal possibilities of becoming attuned to other sentient beings” (p. 1). He quintessentially relates the sense of intercorporeality, the experience of intercorporeality, and its sensibilities to attunement, resonances, and congruency, empathy, sympathy, and care. Finally, from my perspective, Smith’s (2018) and Bai's

(2013) perceptions and standpoints, with an explicit and profound understanding of animism and intercorporeality, with regards to contemplative practices such as meditation, can be an aid for human well-being and allow progress towards a more sustainable future.

It is obvious that mental activities, intellection, thoughts, sensations, images, and emotions use energy. This is the reason for feeling "depleted, listless, and spent," which is called "de-animation" and "disembodiment" (Bai, 2013). This will end in dualism. Bai states that "stopping the continual draining and dissipation of vital energy," and "recharging the nervous system" is a "way to overcome dualistic thinking." To be alive and free, we need to "make [our] mood gentle and [our] mind comfortable, then enter into quietude" while tuning our breath to avoid our mind running off and to save and regulate "the flow of percipient energy" (Bai, 2013). Therefore, to see the world completely alive, sentient, embodied, and animated, we must save our vital energy by contemplative practices and ways. In general, we need to have a pause in our "ordinary consciousness" which will take us to "the state of concentration and absorption," and consciousness (Bai, 2013). These are all the different ways to avoid leakage of organic energy—feeling exhausted and "spent." Bai concludes "when we see, feel, taste, and hear the world differently: more alive, vivid, curious, awe-inspired, present, sacred, meaningful, and so on," animated perception has been achieved successfully. In fact, the goal of contemplative practice and animated perceptions is to achieve "mental freedom and clarity" and "a state of consciousness that is:

> tranquil (in contrast to: noisy, anxious, fractious, frenetic, carving and grasping), spacious (in contrast to: constricted, narrow, tight, stuck, panicky), and full of warm and radiant aliveness (in contrast to: unfeeling, cold and grey, flat, deadened) (Bai, 2013).

This contemplative practice can differ from person to person and from place to place; it can happen virtually, in my view. I believe that the elements and factors remain the same and somehow unchanged, for example, an experience of a sense of intercorporeality, attunement, resonances, and congruency, empathy, sympathy, and care in virtuality—*Virtual Intercorporeality*.

3.1.9. Virtual Reality

Our living in *reality,* in many contexts and from various aspects, has been currently transformed and somehow has been pertinent to virtuality (Liu et al., 2017), such as our presence in a Zoom class. Our presence is real but in a virtual *space*, which, in itself, is real (Liu et al., 2017). “With phenomenology, subject/object boundaries are rendered translucent in the immediacy of the prereflective lifeworld” (Adams & Thompson, 2016, p. 13). We live the moments with our *selves* in reality; however, we simultaneously live those moments (the same moments) with others in virtuality, which is again a reality in itself. Is our reality virtuality or is our virtuality the reality? Maybe the virtuality itself is part of the reality. Maybe the definition of reality is being expanded and reformed by embracing the virtuality and its manifestation in all aspects of our lives. Maybe the definition of reality should be transformed and expanded to embrace the virtual itself. Scholars argue that “even experts are still refining their definitions of terms” (Dede et al., 2017, p. 2). What matters is that “less immersive than VR [virtual reality], augmented reality (AR) and mixed reality (MR) bring layers of data, information and virtual objects into real environments” (Schwab & Davis, 2018, p. 240). Where is our *place* and *space* in virtuality? Where does our learning happen—in a Zoom class or at the SFU Campus class? In reality or virtuality (while the virtuality itself is a reality)? Do we not think that virtuality is now becoming our reality? How is our connection and relationship in a virtual *space*? It is significant how our perceptions, ways of knowing, ways of learning, and practical actions are facilitated and mediated by technologies (Philbeck & Davis, 2019).

Don Ihde (1990) beautifully describes how “our lifeworld obtains new shapes and curves, meanings and trajectories” by technology (Adams & Thompson, 2016, p. 58). Moreover, he situates “human-technology relational analyses in phenomenology’s notion of intentionality” (p. 58). “What kinds of human-technology-world relations does this technology engage?” (p. 58). Embodiment or hermeneutic? I believe both. On the one hand,

> our most primal relation with technology is embodiment. An embodiment relation convenes when a technological artifact becomes an extension of our corporeal self, and is thus “incorporated” as part of our bodily experience. Automobiles, pens, and smartphones all fall into this relational category. The automobile extends our feet, the pen our finger, the smartphone our voice (and our memory, etc.). Here, the technology acts

> as the medium or atmospheric surround through which we may amplify our perceptual senses and extend our bodily capabilities. (p. 59)

We human beings, with our ways of perceiving and experiencing through technology and our bodies, are becoming more connected and considered than before, though we have a sense of disconnection and isolation during a global pandemic. On the other hand, "a hermeneutic relation scaffolds a particular framing of the world and thereby shapes our thinking habits and structures how knowledge is held" (Adams & Thompson, 2016, p. 62). Whatever we understand, perceive, directly experience, and interpret in the connection between the world of technology and the world itself is associated with a hermeneutic relation; for example, how we use technology for an online class; how we share our knowledge through that technology. We may hear each other's voices in a Zoom class—it means that we are present in that *place/space* (in the Zoom class) and also in our *place* (at home or wherever we are) though we might not see each other due to the closed camera.

In real world—real reality—like the SFU Campus class, our place/space is determined. It is the SFU Campus building. However, in a virtual reality like Zoom, people at different locations and places are present at a place/space which is truly not only far from each other but also different from their original places/spaces; destination in less than a second. For instance, to gather at the SFU Campus class, everyone from everywhere must take time to and come to the SFU class/place/space/environment. However, to be together in a Zoom class, everyone from their own places/spaces/environments is able to gather and become *present* at a time in a new place/space/environment—Online/Virtual/Remote Place. This presence does not take *time* for travelling from one place to another place to become present. This place/space/environment does not hold any determined and specific location. Local becomes global and vice versa. It is everywhere. Boundaries are broken.

On the one hand, teachers and students from around the world are able to instantly gather together in a newly defined *place/space/environment* without any actual time travelling or being displaced from their own *place/space/environment* for different educational and professional purposes. This is not a phenomenon that can be explained within classical physics. But on the other hand, our classrooms have shrunk from the architectural, equipped ones to the size of a laptop monitor. People are simultaneously in both locations, in their own location and the aimed one—here and there. From my view, this is quantum. For defining and describing these phenomena, we must refer to modern physics. Now, what is the actual definition of *place/space/environment* in which there is no investment of time in displacement? How do we define it? If we look carefully, we are actually virtually face to face in Zoom rather than at the SFU Campus class. It seems that even the words need to be somewhat updated. It seems that we are on the way to experiencing a new revolution in the near future.

3.2. Reasons for Updating and Adapting to the Fourth Industrial Revolution

> *Learning courses [subjects] are too infrequently updated, and too often not adapted to the Fourth Industrial Revolution. Educational curricula cannot remain fixed as career paths change faster, and are less linear, than ever before. The future-ready curricula must deliver a strong base of foundational linguistic, mathematical, and technological skills. The Forum's 2016 report, The Future of Jobs, noted that the core skills of the 21st century—such as complex problem solving, critical thinking, creativity, collaboration, and digital literacy—are important for enabling people to be flexible enough to adapt to the changing needs of the job market.*
>
> *(World Economic Forum, 2020a, p. 14)*

Klaus Schwab, the founder and executive chairman of the Geneva-based World Economic Forum, introduced the term *Fourth Industrial Revolution* at the Davos meeting in 2016. Schwab argued in his published book, *The Fourth Industrial Revolution*, in 2016, that a technological revolution is underway "that is blurring the lines between the physical, digital and biological spheres" (Schwab, 2017, p. 40). Moreover, according to the American Association for the Advancement of Science, "a strong education in STEM is essential for all students, whether they grow up to pursue a STEM career or just apply scientific reasoning and knowledge in their day-to-day lives" (American Association for the Advancement of Science, n.d.). Therefore, it is important to understand what the Fourth Industrial Revolution is and how it relates to education.

According to Schwab (2016, 17, 18; Schwab & Davis, 2018), there are three main reasons that the Fourth Industrial Revolution differs from the third one which began in the 1960s with the first generation of computers and digital devices. The first reason is associated with the speed of the fourth revolution since "everything is happening at a much faster pace than ever before" (p. 37). Second is the breadth and depth as "so many radical changes are occurring simultaneously"; and finally, "the complete transformation of entire systems" (Schwab, 2016, p. 37). Subsequently, there is certainty and uncertainty with all these new technologies and dramatic changes. For instance, it is significant that the "nature of work across all industries and occupations" will be revolutionized by new technologies (p. 37). However, we are not sure how long it will take and to what extent robots will be substituting in certain work or how fast this substitution will take place in various sectors (Schwab, 2016). In short, the Fourth Industrial Revolution not only swiftly brings us many new and unprecedented opportunities but also has a disruptive and destructive power like the other previous industrial revolutions (Schwab & Davis, 2018; Schwab, 2016, 2018, Schwab, 2021).

This section explores the importance and key scopes of the Fourth Industrial Revolution and portrays its potential impacts on our future life and education. I endeavour to understand why the educational curricula such as physics curriculum and pedagogical approaches should be updated and adapted to the Fourth Industrial Revolution. As such, we need to know what the Fourth Industrial Revolution is and how it will impact us. I will address three sectors of the Fourth Industrial Revolution: physical, digital, and biological groups which are particularly interwoven with technologies. Meanwhile, it is important to mention again that this section will be limited to an understanding of what the Fourth Industrial Revolution is; thus, it will not focus on the negative impacts, deficiencies, and potential critiques. The purpose of this literature review is not to delve into and discuss all the pros and cons of the Fourth Industrial Revolution, its impacts on education, and the implications of technology utilization and automation. This study is for all of those educators who are optimistically interested in knowing our future, its opportunities and possibilities. The importance of significance of *contemporary life* has been already explored with Tyler's perspective (1949). While I strive to understand my contemporary life, the Fourth Industrial Revolution is explored. Therefore, in this section, I attempt to understand the Fourth Industrial Revolution with its size, speed, and scope. I still pursue the reasons that took me to a standpoint in which I believe that we need to update and adapt the educational curriculum and the pedagogical approaches of teaching physics in the Fourth Industrial Revolution and our contemporary life.

We—parents, teachers, administrators, and policy makers—have recently encountered many diverse and intriguing challenges in education. Ways of learning, studying, collaborating, and even thinking are changing rapidly with the COVID-19 pandemic. The World’s Fourth Industrial Revolution is happening, and it is totally different from the past revolutions due to its size, pace, and scope (Schwab, 2016, 2018; Schwab & Davis, 2018; Schwab & Malleret, 2020). Consequently, I, as an educator, deem that students’ content learning and teachers’ pedagogical approaches and their involvement with digital devices and technologies are in a state of flux.

The difficulty that many schools and educational institutions are experiencing in attempting to discuss these issues is a further sign of how we are not prepared to adequately and proactively recognize the forces of change in education. Maybe COVID-19 is a thrust, a cause of transformation in global management and a means to support the completion of the Fourth Industrial Revolution (Schwab & Malleret, 2020). It seems that the traditional model of teaching and learning must be reformed and revolutionized with technology so strategies can be developed and become adapted to the 21st century. A number of important changes need to be made. The first step is associated with our ways of thinking, which would help behavioural change, enhance progress and achievement in learning, and, finally, aid in better and faster reform and adaption.

We have all realized how the world—Europe, Asia, the Middle East, North and South America, and so on—has dealt with and continues to deal with the COVID-19 pandemic. I would like to return to the past—the regressive moment of *currere*—and review the world’s experience of COVID-19. The city of Wuhan was at the centre of the outbreak in December 2019. More and more cases were diagnosed in the first few weeks of 2020. In January of that year, Wuhan and nearby cities in Hubei province went into strict lockdown. More than 50 million people were placed under mandatory quarantine as revealed by the American Association for the Advancement of Science in 2020. As such, most countries put citizens into mandatory quarantine and only food stores and pharmacies remained open. All public sector employees with non-critical and non-essential jobs were sent home. Most countries closed every school and educational institution.

Children were being kept home from school. Businesses were closing their doors. Banks temporarily closed branches. Most physical and social visits and services were banned and/or limited. Inquiries were mostly responded to online or by phone. Moreover, there are still many difficulties and challenges regarding at-risk populations, food insecurity, mental well-being, and other vital services in communities. We wake each morning wondering what the day will bring. It is January 2022, and the world is still dealing with the COVID-19 crisis.

However, with all these complexities and challenges, students, teachers, and public sector employees initiated online learning and teaching, working promptly, carefully, and adequately. This transformation has not only happened in education but also in different businesses (Schwab & Malleret, 2020). We have experienced a huge *shift* towards technology, the digital environment, and an online connection, interaction, and collaboration. While physical and social gatherings have been banned in some countries, people virtually gather through the internet and other technologies. The physical presence of students at schools is converted to virtual ones via video conferencing software by digital devices and internet networks. Indeed, we have become familiar with many useful collaborative software and platforms during the past two years. To sum up, a *shift* and *revolution* seems to be happening, and the crisis of COVID-19 is reshaping everything, especially education and the learning environment (Weissbourd et al., 2020; Schleicher et al., 2021; Schleicher, 2020; Luthra & Mackenzie, 2020).

Truly, these transformations could not have happened without a worldwide pause in different sectors such as education and business. But people have experienced stress and anxiety and are impacted by the change. It seems there has been a stressful and painful suspension for some people as there are many reports of deaths, shortages, and closures (OECD, 2020c; Schwab & Malleret, 2020). Although it has caused distress for some people (Schwab & Malleret, 2020), there is a reshape and shift towards development with digitalization, automation, mechanization, computerization, telecommunication, and cybernation (Schwab, 16, 17, 18; Schwab & Davis, 2018; Philbeck & Davis, 2019). Consequently, computer networks, digital devices, and the internet are becoming as important as our daily basic needs such as food, clothing, and housing (Schwab, 2016, 2017, 2018; Schwab & Davis, 2018).

Without a doubt, these are unsettling times, and we are facing some challenges related to the pandemic. People have placed their trust in states and organizations. We all see and hear stories in this regard. Financial, political, medical, and educational institutions are all performing their parts. For example, great support comes from different financial institutions relaxing payments on loans or mortgages, and they are ready to help business clients manage through today and plan for the future. Public health officials, provincial and federal governments, organizations, and NGOs all are actively trying to manage and control the outbreak. Virtual and digital infrastructures are ready for evolution, such as 5G.

It is true that technology will impact us with a destructive effect as computers and automation substitute for some jobs. Thus, employees have to be laid off or relocated elsewhere according to their skills and knowledge (Schwab, 2021; Schwab, 2016, 17; Schwab & Davis, 2018; Schwab & Malleret, 2020). Nonetheless, this negative impact with capitalization increases the demand for new goods and services which will consequently create new occupations, businesses, and industries (Schwab, 2016, p. 38). Though there is a point of view that technological innovation may destroy some employment opportunities, it has always replaced them with new ones with different activities and skills (Schwab, 2016, 2017, 2018, 2021; Schwab & Malleret, 2020; Schwab & Davis, 2018). Some of these new opportunities in the field of quantum will be mentioned in Chapter 5. Studies show that 670,000 US jobs were lost to robotics between 1990 and 2007; however, new job opportunities and markets were created in their place (Meyerson, 2015). My optimism leads me to believe that technology and digitalization have always made everything easier and faster than before. For example, if we look back to the second industrial revolution or before that, we understand how the invention of electricity and the light bulb changed our lives by opening new doors towards a better future with new inventions and new opportunities (Philbeck & Davis, 2019). In sum, humans, governments, societies, and countries have always benefitted from each industrial revolution and its positive impacts.

The results of studies that I reviewed demonstrate that a new generation of robots will be collaborating with human workers in repetitive or dangerous tasks, 24 hours a day, seven days a week, without needing health benefits, vacation, and sleep (Meyerson, 2015; Schwab & Davis, 2018). For instance, nurse robots are being tested in Japan, helping patients out of bed and supporting stroke victims by controlling their limbs as claimed by Bernard Meyerson, Chief Innovation Officer at IBM Corporation in the US (Meyerson, 2015). However, though there is a significant maintenance and repair cost involved, new job opportunities and new required skills are being created. The transition from muscle power to mechanical power and now enhanced cognitive power illustrates the capabilities of human beings to improve the ways of learning, creating, and living. The revolution and emergence of technology in education are a catalyst for change toward development through innovation and modernization (Plaisent et al., 2020; Schleicher, 2018, 2020; Schleicher et al., 2021; OECD, 2021b, 2020c).

Technological drivers of the Fourth Industrial Revolution are organized into three groups: physical, digital, biological (Schwab, 2016, 2017; Philbeck & Davis, 2019; Schwab & Davis, 2018). Physical technologies are autonomous vehicles, 3D printing, advanced robotics, and new materials. The “internet of all things” is a bridge between physical and digital groups (Schwab, 2016, p. 22). There is a digital equivalent for all that is physical (Schwab, 2016; Schwab & Davis, 2018; Reaves, 2019,). Moreover, Schwab (2016) argues that biotechnologies are rapidly emerging with innovations and demonstrating considerable progress in genetics and so forth, such as digital healthcare, sensors, transplant organs, and designer babies. Biological, physical, and digital groups are interrelated by 3D printers and printing the liver-cell layers and humans’ live tissues (Schwab, 2016). In short, these three groups are significantly interconnected and the gap between them has dramatically decreased (Schwab, 2016, 2017, Schwab & Davis, 2018; Philbeck & Davis, 2019).

For instance, autonomous cars such as driverless cars, trucks, drones, aircraft, and boats have emerged. By importing technologies like sensors and artificial intelligence (AI), the capabilities of all these machines have improved rapidly (Schwab, 2016; Schwab & Davis, 2018). For example, drones, with the ability to sense and respond to their environment, are able to check electric power lines or deliver required supplies to different locations (Schwab, 2016; Schwab & Davis, 2018; Philbeck & Davis, 2019). Moreover, they are able to fertilize and water efficiently in agriculture.

With 3D printing, by using a digital template and loose material, an object can be built into a three-dimensional shape like wind turbines, medical implants, integrated electronic components, circuit boards, human cells and organs (Schwab, 2016; Schwab & Davis, 2018). In addition, researchers are working on 4D products that are able to respond to environmental changes like heat and humidity and are being utilized in clothing or footwear and human body adaptable implants (Schwab, 2016; Schwab & Davis, 2018).

Advanced robots are being utilized in various sectors such as automotive, agriculture, health (for nursing) and the home (for doing chores). Schwab claims that more flexible robots with complex biological structures, functions, and sensors will collaborate with humans. Robots are able to understand, respond to their environment and remotely access information via the cloud and network connection (Schwab, 2016; Schwab & Davis, 2018). Researchers, practitioners, and leaders reveal that they are entirely able to collaborate with humans, which is called human-machine collaboration (Schwab, 2016; Schwab & Davis, 2018).

Lighter and stronger, recyclable, and adaptive new materials are coming to markets such as smart materials with self-healing or self-cleaning abilities (Li et al., 2021; Schwab, 2016), for example, 2022 BMW IX full electric car with self-healing abilities. Advanced nanomaterials are being produced, like graphene, made of carbon, 200 times stronger than steel and a million times thinner than a human hair, and an efficient conductor of heat and electricity (Isaiah, 2015; Schwab & Davis, 2018). These are the most expensive materials on earth, such as the new generation of recyclable polymers (Isaiah, 2015; Schwab & Davis, 2018).

Digital devices like smartphones, computers, tablets, and smartwatches are all connected to the internet. The number of these devices will increase to more than a trillion (Schwab, 2016, p. 22). Smaller, cheaper, and smarter sensors are being utilized in clothes, homes, accessories, cities, transport, and energy networks. Therefore, activities and assets will be monitored and optimized drastically and remotely in manufacturing (Schwab, 2016; Schwab & Davis, 2018). For example, packages can be equipped with a sensor, transmitter, or radio frequency identification (RFID) which allows a company to track the package or supply chain and see where the package is, or how it is performing, or how it is being used, and so on (p. 22) like Amazon. The ways that individuals and institutions engage and collaborate will be radically revolutionized with new approaches to digital technologies (Schwab, 2016, 2017, 2018, 2021; Schwab & Davis, 2018; Philbeck & Davis, 2019). Technology will be an aid to match supply and demand in a low-cost way like Uber, which doesn’t own any vehicles; it means no assets, but it owns the platform (Schwab, 2016).

Furthermore, the outcomes of studies confirm that the Human Genome Project resulted in sequencing, activating, and editing genes (Schwab, 2016; Schwab & Davis, 2018). Schwab claims that $2.7 billion was spent on this project over ten years. “With advances in computing power, scientists no longer go by trial and error; rather, they test the way in which specific genetic variations generate particular traits and diseases" (Schwab, 2016, p. 24). Synthetic biology will enable us "to customize organisms by writing DNA" (p. 24) which will have a significant impact on medicine, agriculture, and production of biofuels. Therefore, effective healthcare will be revolutionized by determining individual genetic make-up through sequencing machines informed by a tumour (p. 24). The studies will develop targeted therapies and improve treatment outcomes through smart medicine (White, 2002; Schwab, 2016; Arnault, 2014). By editing and modifying any cell type of organism, the creation of genetically modified plants, animals, and humans is precisely, practically, easily, and efficiently done, which is different from "the genetic engineering practised in the 1980s" (Schwab, 2016, p. 25). For example, modified animals in different environmental conditions (in significantly high or low temperatures) can be raised on a different diet, which is more economical and vital for the people of those areas (Schwab, 2016). In addition, modified food crops can be grown easily in diverse temperatures and weather conditions like drought (Schwab, 2016). Indeed, editing genes will revolutionize medical research, treatments, and resources. By modifying and editing genes of plants and animals, a new generation of medicines and forms of treatment will be produced (Schwab, 2016; Schwab & Davis, 2018). For instance, "Cows are engineered to produce in its milk a blood-clotting element, which hemophiliacs lack" (p. 25). Likewise, researchers are able to engineer the genomes of pigs (Schwab, 2016; Schwab & Davis, 2018).

As mentioned before, the physical, digital, biological sciences are interrelated and interconnected. As well, 3D printing and "3D manufacturing will be combined with gene editing to produce living tissues which is called bioprinting. This is being utilized to generate skins, bone, heart, and vascular tissues" (Schwab, 2016, p. 26). As such, transplant organs are used and created by printing liver-cell layers (Schwab, 2016). In addition, neurotechnology and brain sciences have been the most funded research programs over the past few years (Schwab & Davis, 2018; Schwab, 2016).

Though some techno-optimists believe that technology has been disruptive, they have observed that it has always been an aid to improve knowledge, precision, pace, efficiency, productivity, and has increased engagement, connection, and communication (Schwab, 2016, 2017, 2018, 2021; Schwab, & Davis, 2018; Philbeck & Davis, 2019; OECD, 2021b, 2020a, 2020b). They will be useful in "identification, location and behavior monitoring, and health functions" (Arnault, 2014). Technology has also increased goods and services demand and created new types of jobs (Schwab, 2016, 2021; Schwab & Davis, 2018). It is important to note that the negative impacts of these vast changes are not negligible, as with the previous industrial revolutions (Schwab, 2016; Schwab & Davis, 2018). However, as human beings, we have an incredible capacity for adaptation, ingenuity, creativity, and innovation while technologies have the power to unleash a new era of prosperity (Schwab, 2016, 2017; Schwab & Davis, 2018).

The World Economic Forum's Global Agenda Council (2015) conducted a survey on the future of software and society and released the results in the "Deep Shift, Technology Tipping Points and Societal Impact." About 800 executives and experts from the information and communication technology sector participated in the survey (WEF, 2015; Schwab, 2016). The results revealed that 91.2% of the participants expect that "10% of people will be wearing clothes connected to the internet" by 2025 (WEF, 2015, p. 7); 86.5% expect and look forward to using "the first robotic pharmacist in the US" by 2025; 76.4% expect to use "the first transplant of a 3D-printed liver" by 2025; 80.7% and 78.8% of the executives and experts expect "90% of the population [will utilize] smartphones," and "90% of the population [will have] regular access to the internet," respectively (p. 7). By 2025, 84.4% of participants expect "80% of people [will have] a digital presence on the internet"; 91% of the directors and experts expect "90% of people [will have] unlimited and free […] storage"; and 78.2% of the specialists and executives expect driverless cars will equal "10% of all cars on US roads" (p. 7).

Undoubtedly, we all recognize that the way we live, study, and learn has changed over the past decade (OECD, 2021b, 2020c, 2010a). Now, we can see how schools and educational institutions have quickly and smoothly been updated with technologies and collaborative software such as Zoom, Microsoft Teams, Blue Jeans, and so on during the COVID-19 pandemic. Administrators, educators, teachers, and students are adapting to technology utilization and digital devices for virtual teaching, learning, and collaborating more than ever. Indeed, "We are wedded to our phones, our tablets, and our laptops" (Vandenberg, 2020, p. 194). It is inspiring how people continue meeting, working, learning, and shifting everything from the physical to the virtual with the help of digital devices, internet networks, and online resources (Reimers et al., 2020). Students are able to connect with their teachers from different locations, even from different countries. Teachers initiate their online classes with different software via video conferencing, Zoom, other available online platforms, and resources. In turn, students try and explore the experience of learning online and being engaged and connected with teachers and classmates virtually though they have missed school and the class environment too. Learning and studying have become paperless, and meetings are held via video conferencing. Everything these days is happening with the tap of our fingers and the help of technology.

According to a report by the World Economic Forum in 2016, the Fourth Industrial Revolution, like the previous industrial revolutions, is expected to disrupt the current industries and businesses; thus, about 5 million jobs will disappear due to digitization and technological emergence in 2020 (Alos, 2018) and, according to the World Bank, “66% of all jobs in developing nations” will be replaced by automated machines (Clifford, 2016). However, Schwab, in his published book in 2016, claims that the Fourth Industrial Revolution is empowering and human-centered rather than divisive and dehumanizing. For example, the collaboration of humans and robots to conduct and complete a task more quickly does not necessarily mean that robots are replacing humans. It is important that humans are capable of thinking critically, solving problems, being innovative, coming up with new ideas, and being creative (Alos, 2018; Schwab, 2016; Schwab & Davis, 2018). These are the essential and even vital skills which must be taught and practised with our students to thrive in the future (Buckley et al., 2021; Vincent-Lancrin, 2019; Schwab, 2016; OECD, 2021b).

In a report by the World Economic Forum in 2020, the top ten skills that students need to learn in order to succeed not only in their education but also in their future careers are as follows: Complex Problem Solving, Critical Thinking, Creativity, People Management, Coordinating with Others, Emotional Intelligence, Judgement and Decision Making, Service Orientation, Negotiation, Cognitive Flexibility (WEF, 2020a; Alos, 2018; Schwab & Davis, 2018). Furthermore, the physical, biological, and digital interconnections in technologies and scientific innovations revealed and discussed in this chapter are based on a knowledge of quantum mechanics. Here is where educators, teachers, and curriculum developers play a significant role in teaching and supporting students in a way that they are able to practise and learn the needed scientific knowledge and skills to achieve their goals in education, life, and future career (Schleicher, 2018; OECD, 2021a, 2021b, 2019a, 2020b; Milner-Bolotin, 2017a; Beers, 2011). Now, are we able to teach these skills with outdated and poorly adapted curriculum and pedagogy in the Fourth Industrial Revolution? Are we and students prepared and ready for all these *changes*? Do we need to promote STEM in education after understanding and experiencing the Fourth Industrial Revolution? Now, with all the aforementioned information, what have we done and planned for? What do we have to do for the education of the new generation? How do we prepare ourselves and our students for the future? What is the first step?

3.3. Ethics and Experience as/at an Intersection of Epistemology and Ontology

From my point of view, the first step of learning and preparing for a better future is referring to scholars who tactfully and quintessentially speak to the growing need for ethics and consciousness via epistemology and ontology for human life and society (Barad, 2007; Bai, 2003, 2014). They address some of the hesitations and barriers in reaching that level of awareness and knowledge. My immediate thoughts after reading and understanding their standpoints were to connect the views to our contemporary life and the era of artificial intelligence to examine how their perspectives respond to the future of education and the current status quo with a global pandemic. I started exploring my concerns and answering my questions throughout the research papers while I was carefully attempting to *perceive* the concepts. By continuing, moving forward and truly delving in, I realized that I was unconsciously trying to connect everything to everything as "everything exists in connection with everything else" (Bai & Cohen, 2014, p. 599). These connections can be consciously perceived as analogous and justified with knowledge of *relativity* and *quantum physics*. This is what Barad (2007) has intentionally focussed on and reflected in her studies. For example, if we look at them carefully, mathematics and the physical and natural sciences are related to social sciences and other disciplines in practice, like gender equality and equity. Politicians and leaders have always relied on scientists' knowledge and support. As emphasized by Barad (2007) in science education, there must be ethical uses of scientific discoveries to lead society towards a more inclusive, desirable, knowledge-based, and sustainable future (Barad, 2007).

Bai (2003) states that "to speak of experience is to speak of the perceiver and the perceived as an inseparable unity. Experience is this unity" (p. 44). By questioning, assessing, evaluating, reasoning, analyzing, crystallizing, and drawing conclusions on my lived experiences, I was checking myself to know what I was, what I had, what I have been, what I know, and, eventually, what I will be (become). I am wondering and questioning whether my lived experiences are being counted as my knowledge and if they are what I know in my life. Are they reality? Are they what I should have perceived? Or do I need to practise becoming a better "perceiver" and vitalize my "self" on the "way of my life."

Indeed, "in the act of perception, the perceiver and the perceived arise together simultaneously" (Bai, 2003, p. 44). A better *perceiver* holds more *perceptions* and approaches a greater level of awareness and consciousness, which counts as knowledge. Knowing and understanding reality matters here. "In experience, there is never a perceiver independent of the perceived, and vice versa" (p. 44). Bai and Cohen (2014) assert that epistemology is "how we know what we know, and what counts as knowledge" (p. 599). They believe that "epistemology follows from ontology" which is "how we understand *reality* and being" (p. 599). The way we understand the reality matters here, then. Moreover, they explicate that epistemology and ontology can lead the perceiver towards ethics, and perceiving without fear, ignorance, greed, anger, anxiety, irritation, and impatience, which all are poisonous for human consciousness. This is the reason that Barad (2007) brings ontology, epistemology, and ethics together and simultaneously considers them in scientific practices. According to Bai (2003), "It is ultimately impossible to separate the perceiver and the perceived" (p. 44), like what an individual perceives from the impacts and critical challenges for now and the future. However, in each experience and era, we must ethically continue living our life and trusting ourselves "to cause and effect as-it-is," perceived and conveyed by Bai and Cohen (2014, p. 598).

3.4. First Important Conclusion for New Initiations

Reality matters. There would be catastrophic consequences if technologies fail or are turned off as everything in our society relies upon connected technologies from hospitals to schools. Technology is leveraging opportunities and personalizing learning (National Science Foundation [NSF], 2020; Schleicher, 2018, 2020). "Distinctions between formal and informal learning are no longer valid as society turns itself entirely to the power of the machine" (Schleicher, 2020, p. 42). Education takes place everywhere, anytime. AIs are advancing fast, and robots are joining us (Schwab, 2016; OECD, 2021b). Digital devices and technology are becoming part of our *bodies* (Schwab &

Davis, 2018; Schwab, 2016). The Fourth Industrial Revolution is on our way (Schwab, 2016, 2017, 2018; Schwab & Malleret, 2020; Philbeck & Davis, 2019; Schwab & Davis, 2018; Reaves, 2019). We may replace challenges with possibilities while taking care of our well-being with diverse contemplative practices during the crisis. In short, while ethical parameters are regarded in utilizing scientific knowledge in the 21st century (Barad, 2007) the fourth industrial and digital revolution shapes our future and expands our horizons of possibilities and opportunities (Schwab, 2016, 2017, 2021, Schwab & Davis, 2018; Philbeck & Davis, 2019).

In fact, it is not an easy shift. It is benevolent of a pandemic over pandemic; one needs to be changed by our *selves,* and another is changing the world. With these pandemics, people are out of their comfortable, normal existential zone and are experiencing different absences and tensions which have resulted in their existential lack. Some are feeling helpless and powerless. Subsequently, some are trying to *fight*, some are trying to *flee*, and some are in a *freezing* zone (Bai & Cohen, 2019). Indeed, "world change is mirrored by self-change" (Bai & Cohen, 2019, p. 22). The integration of epistemology, ontology and ethics is significant. Scholars suggest that one of the effective solutions for surviving is attunement and flow, which is not an easy practice for some people.

Moreover, people with different perspectives and lenses look at the world and the changes differently. For holding these different lenses and reflecting different perspectives, I believe that permission is needed. Below, I refer to a scholar who first inspires me to think about different lenses, changes, and various perspectives, then grants such permission. I apply his viewpoint not only in my study and doctoral thesis but also in my practices. I consider this quote as an open-ended statement about change from Kenneth Tobin.

> We know from experience that what is happening depends on who you ask and how you choose to look at the world. With different lenses you see different views and derive different understandings. It behooves us to continuously change our lenses as well as explore difference through the same lens. (Tobin, 2020, p. 17)

Here, from my viewpoint, we first need to change our lens; second, we need to want and allow to change; and, last but not least, we need to become pragmatic optimists in the Fourth Industrial Revolution. The question remains: Do we find Zoom classes as effective as the in-person and face-to-face classes at the Surrey Campus—from both students' and teachers' perspectives? Do we think that in-person and hands-on activities have been left at the SFU Surrey Campus? Our learning places/spaces/environments are being changed. Home environments serve as safe learning environments for students and working environments for teachers and parents (Schleicher, 2020). New experiences push the traditional and old boundaries back. I have highlighted the changes and what are adequate ways of sustaining and enhancing the quality of learning and teaching while underlining the importance of some particular contemporary scientific knowledge and technologies and their roles in current and future careers. The 21st-century skills are key factors in our future prosperity while collaboration and cooperation are central canons for the education we value for today and tomorrow (Schleicher, 2018; OECD, 2021a, 2021b, 2019a, 2020b; Beers, 2011). I wonder whether we can keep our curriculum and pedagogy unchanged and outdated. It is significant that new approaches and adaptions in education are needed due to the recent experienced changes and challenges during the COVID-19 pandemic (Schleicher et al., 2021; Schleicher, 2020). Eventually, according to the realities and points mentioned in this chapter, I as a female science educator from an underrepresented field of science—physics—underscore the need to redesign not only our pedagogical approaches and teaching styles but also curriculum for 21st-century students.

Chapter 4.

My Perceptions of Gender Equality and Equity as a Female Science Educator

4.1. Stressing a Longstanding Issue

Due to women's underrepresentation, not only among science, technology, engineering, and math graduates but also among the scientific, technical, and educational leadership sectors, there is a fundamental gender parity issue and a huge gap in STEM-related careers (Barad, 2007, 1995; WEF, 2020b, 2021b; Milner-Bolotin, 2015; Ceci, 2014; Sandberg, 2013). These discrepancies are caused by destructive *stereotypes*, a *lack of role models*, and antagonistic work environments which subsequently cause significant social, cultural, political and economic consequences (Milner-Bolotin, 2015; Ceci, 2014; Sandberg, 2013).

4.2. Ways of Seeing and the Effect of Seeing Consciously and Contemplatively

A careful inspection of the contemporary literature suggests that most of those who study gender and gender-related issues trace their social, ethical, intellectual, educational, rational, cultural roots, experiences, and reasons to reflect on underrepresentation for females and overrepresentation for males in various fields (Kuschel & et al., 2020; Ceci et al., 2014; Barad, 2007, 1995; Sandberg, 2013). From my point of view, it is undeniable that *cultural* views, perspectives, styles, and roots have been a great—perhaps the single greatest—influence on this problem. With help from Annie Dillard (1974) in "Pilgrim at Tinker Creek," I tacitly offer a view of seeing and looking at this issue. I review and examine how and the extent to which natural phenomena and societal impacts can enable us to differently and spontaneously see the reality, perceive the diversity, admit the presence of the woman, and erase their/her underrepresentation in societies. I succinctly express my viewpoint and phenomenologically demonstrate ways of seeing and looking at the issues with the help of *light* phenomena and its concept in physical science while it is implicitly interwoven with social science and culture.

In exploring these issues, I refer to both my current and past lived experiences. I subtly utilize Pinar's method of *currere* and self-reflexivity within the processes of education (Pinar, 2004, p. 35; Pinar, 2019). I posit myself in a “biographic situation,” as argued by Pinar and Grumet (1976). I am from a male-dominated milieu. Though the majority of my peers were females, males dominated the related positions and careers in my field after I graduated. More men were in educational and leadership positions and were not an adequate and encouraging role model for underrepresented women and young female students.

I have to say that due to the cultural differences—beliefs, norms, values, and religions—I was not sensitive to this issue. Like a blind person, I was used to feeling the waves of water with my palm, fingers and hands. “I am blind as a bat, sensing only from every direction the echo of my own thin cries,” Dillard (1974) states (p. 25). This way of seeing for me continued until the initiation and completion of my studies at the University of British Columbia in Canada, which truly did not only reform my perspectives with regards to male and female domination but also changed my ways of seeing, perceiving, contemplating, and comprehending the issues related to gender equity and gender parity. “How is the future present in the past, the past in the future, and the present in both?” (Pinar, 2004, p. 37; Pinar & Grumet, 1976, p. 60; quoted in Pinar et al., 1995, 520). It is thrilling for me to reflect on how my background knowledge, logic, lived experiences and education in Iran and Canada all together led me towards seeing differently and being enlightened—a new way of seeing—which is reflected via this study.

I can see …; I am not blind. I can hear …; I am not deaf. Are these my perceptions or the reality that everyone able to see is not blind or who is able to hear is not deaf? Can I be called blind when I have vision and the ability to see? Can I be called deaf when I am able to hear sounds? What is the definition of blindness? What is the definition of deafness? What are our interpretations of blindness and deafness? How are our relations, collaboration, and cooperation with the blind or the deaf (from our viewpoint blind or deaf) persons? What is the distinction between an experience of a moment when one is physically blind (that is, without vision/sight) and not able to see a fact, with one who is not physically blind (who has vision/sight) but either does not see the fact for any reason or does not wish to see the fact again for any reason? These are the questions and concerns that I phenomenologically and epistemologically examine through the lens of the physics of light phenomenon as well as the social sciences, and associate and thoroughly analyse them with a view to inform and enable gender parity and equity in physics education.

Marius von Senden in “Space and Sight” reflects on the stories of blind patients, women and men of all ages who had been operated on by Western surgeons across Europe and America. Senden asserts that many doctors examined the “patients’ sense perceptions and ideas of space both after and before the operations” (Dillard, 1974, p. 25). The majority of patients of both sexes and all ages had no idea of space, form, distance, size, depth, shape, height, shadow, colour-patches, dimensions and so on (Dillard, 1974). For instance, one patient, after the bandages were removed, described a human hand as “something bright and then holes” (p. 28) while the other one names “the tree with the lights in it” (p. 28). They are “dazzled by the world’s brightness and [keep their] eyes shut for two weeks” (p. 29). It seems they struggle with acceptance and adaption to their new reality.

In *Pilgrim at Tinker Creek,* Dillard (1974) reveals that doctors found the patients' experience of seeing, conceiving, and reasoning the new vision and perceptions very overwhelming and oppressive. Their difficulties and struggles in reasoning subsequently impacted their realization and perception. Their world (size of this world) had previously been in the power of their hands and their sense of touching and feeling (Dillard, 1974). The extent to which a blind person utilizes touch and feel is admittedly and significantly different from those who are not blind since they benefit from another kind of ability from birth, not available to others. The oppressed do not have any perceptions and experiences of that benefit and ability since they have either not been provided with that benefit and opportunity or have not been able to have it at all, like the abilities that people are born with. Therefore, the oppressed “refuse to use their new vision [ability and opportunity], continuing to go over objects with their tongues [returning to previously perceived and experienced world], and lapsing into apathy and despair [becoming reluctant and disappointed]” (Dillard, 1974, p. 27).

Moreover, the significant point is that “the child [human being] can see, but will not make use of his sight [ability, opportunity, and experience]” (Dillard, 1974, p. 27) since what he or she sees is not compatible, aligned with, or similar to that which is previously conceived and experienced. This is something new and astonishing but unfamiliar and difficult. Becoming and being able to see (having vision and sight) is a gift, blessing, and unbelievable ability. However, this is the belief and viewpoint of someone who has always been able to see since birth, not the blind person's view. This is why a twenty-one-year-old girl, after the operation, "shuts her eyes whenever she wishes to go about the house, especially when she comes to a staircase [metaphor of lives up and down] and that she is never happier or more at ease than when, by closing her eyelids, she relapses into her former state of total blindness [return to the comfort zone and easy formerly experienced way]" (Dillard, 1974, p. 28).

Though it is challenging, "some do learn to see, especially the young ones" (p. 28). This arguably develops both advantages and disadvantages. By adapting, on the one hand, their lives are being changed, and on the other hand, their "characteristic serenity" is being lost as they are embarrassed about their old habits and attitudes (Dillard, 1974). Moreover, they lose their concentration as they are being confronted with many new things throughout their new experiences. They earlier had a different view and perspective of the matters and the issues. Their perceptions and notions were totally unlike what they currently hold and acquire. However, the majority of the encountered and realized diversities and distinctions may bring them a sense of curiosity and passion which would satisfy them for adaptation and acceptance. Eventually, without doubt, after some while, they will vigorously assent to and acknowledge the beauty and benefit of what they see and experience, and what they will subsequently see and experience in the future.

Furthermore, "many newly sighted people speak well of the world and teach us how dull is our own vision" (Dillard, 1974, p. 28). They declare, confer, and reflect on what they perceive in the world, which those with sight have already been observing and experiencing. They vigorously and sometimes differently explore and see what we have not explored and seen though we are able and sighted. They are at the beginning of their own seeing processes while they are no longer young. I am talking about females from male-dominated societies. I am talking about young people who do not hold a fixed notion and perception as strong as older people do. Thus, age subsequently and significantly matters here. The adolescents are being amended quickly, and resistance is scarcely being manifested from them.

Indeed, sighted people entering the darkness have no memory of it until visible light enters, even though in darkness, light still exists all around. Undoubtedly, in the darkness, sighted and unsighted people are alike. A sighted person, like a blind person, can only name a tree on taking hold of it but has no idea of its size, shape, and height. However, when it comes to the darkness, walking, moving, perceiving, and acting is much easier for the unsighted person than the sighted one. Darkness is something familiar to the unsighted—they are used to it. I believe that unsighted people will accomplish, achieve, and respond to their environment in the darkness better than sighted people. There is a lot in this. Now, the sighted person has no idea of what they must do and what or how to perceive. It is rational that they need visible light for seeing and achieving. "Then maybe we all could see colour patches too, the world unraveled from reason, Eden before Adam gave names" (Dillard, 1974, p. 30).

What kind of light and which characteristic and properties of light would help them proceed and succeed—the electric part (an oscillating electric field) or the magnetic part (an oscillating magnetic field) of the light or both (electromagnetic light). What is this light at all? Is it energy or particle? How does it behave? How should we observe and see it? How capable is this light? What does and can it do? What is the actual reason for seeing or not seeing? Can we see without light or not see with light? Is any kind of that conducive? Is light enabling or hindering (everyone may just consider the physical aspect and power of *light;* however, there are social, ethical, and cultural facets too)? Is this *light* worth knowing, learning, and utilizing (from any aspects)?

Are there any harmful and damaging lights? Moreover, are all types of lights visible for us? Are we sure that we see all that we ought to see? Are we sure that what we see is real and not an illusion or an unreal perception? Are we truly certain that something that seems broken or bent is actually broken or bent in that environment, or does it only seem broken or bent because of the light? Does it seem shallower because of the light? Are we certain about the effect of light in various environments? Eventually, are we able to create and cause light or be and become light itself? Are we able to light, lighten, enlighten, and brighten …?

> I cannot cause light; the most I can do is try to put myself in the path of its beam. It is possible, in deep space, to sail on solar wind. Light, be it particle or wave, has force: you rig a giant sail and go. The secret of seeing is to sail on solar wind. (Dillard, 1974, p.33)

Notwithstanding Dillard views, from science and a scientific perspective, humans cause and create light but not visible one though an infrared camera could just detect their infrared light emissions. We need to examine the frequency of the infrared light emitted from every male and female individual. Maybe these lights interfere with each other (a metaphor of collaboration) and create constructive and destructive environments/spaces (for men and women) and eventually sometimes create a beautiful pattern (great outcome from their collaboration and work together). This is the power of light which is still under the scientists' observations and investigations. This is light which supports and provides both the sighted and unsighted with opportunities: I am wondering about the infrared lights emitting from men and women; I am wondering whether the gaps are due to the frequency differences not social and cultural *inequality* and *inequity*.

Studies reveal that an inquiry-based learning approach (Minner et al., 2010) in teaching optics has a significant effect on students' physics learning and their engagement in a science classroom (Carli et al., 2021; Maley, 2013; Tsivitanidou, 2021). However, this is not the point that is being drawn from my questions related to light, as there are more *perceptions perceived* by physicists, philosophers, and theorists in the physical sciences. I cannot say enough about the power of light where a theoretical physicist, philosopher, and feminist theorist like Karen Barad uses her knowledge of quantum mechanics and optics, optical phenomena like reflection, refraction, and particularly diffraction, to put forward and discuss more ethical and social issues like gender gap and disparity in mathematical sciences (Barad, 1995, 2007, 2014). She elaborates on Donna Haraway's perspective and how her suggestion of the physical phenomena—reflection and diffraction—inspired her to think about the differences. Haraway uses the phenomena as metaphors and believes that diffraction, due to its creation of patterns, is more likely attuned to *differences*, whereas the metaphor of reflection is exactly associated with mirroring and reflecting the sameness (Barad, 2007, p.71, 72). In reflection, just by changing the angle of view or angle of the reflector, a different amount of the reflected *reality* or different parts of the *reality* can be seen.

As an illustration, considering water waves as a tangible example, diffraction is the bending of water waves around an obstacle or edges of the openings on the shore. Diffraction is a property that is demonstrated by all kinds of waves like sounds and lights. For instance, diffraction phenomenon is the reason that we can hear the conversation in the next room even though we cannot see the sources of the sounds. Diffraction only occurs when the wavelength of the waves (water, sound, or light) is close to or equal to the size of the gap (opening, slit, object or obstacle). It means the size of the gap and wavelength of the waves matter for causing diffraction though the size of the gap and diffraction does not affect the wavelength. It seems wavelength is an innate property of the wave. If the gap is much wider than the wavelength of the waves, then no patterns of diffractions are created, and the waves stay the same until damping and dying. Francesco Grimaldi, the Italian mathematician and physicist, was the first scientist who carefully sighted, observed and discussed the diffraction of light (Barad, 2014).

This is an acknowledged reality, that the sighted and unsighted can see because of *light*—either visible light or other lights: light of knowledge, light of contemplation, light of consciousness, light of hope, light of passion, light of love, and light of life. However, certainly not every sighted person can see the lights. I would like to go beyond classical conventions and theories; even particles (a particle), persons (a person) can be and behave like light. All could be justified by *Relativity*. This is science though these are metaphors: light of philosophers, light of scientists, light of elders. “It is also a call to philosophers of physics for a renewed effort to make quantum theory understandable” in the 21st century (Vermaas, 2017, p. 245). This is truly the light—a kind of energy—which helps us and enables us to see the visible and invisible (differences), feel and perceive the tangible and intangible (differences), comprehend the known and unknown (differences), practice, experience, attain, and absorb the wanted and unwanted (differences) with positive and high energy by its reflection from, refraction in, and finally diffraction at edges and boundaries, hard to see and hard to understand, the quantum of light. Indeed, Light is (a) knowledge (partially discovered) since it existed in the past and will support us in the future—light of knowledge of quantum of light. A knowledge which the “foundational questions in quantum theory have been left primarily to philosophers” (Barad, 1995, p. 69). Undeniably, light has power (the amount of energy transferred or just granted in a particular time to …), and power manifested like light can be both constructive and destructive (Barad, 2007); it all depends on how the interference happens in between.

But between what? Maybe we have to say *who* here. Truly, in the natural and physical sciences, not seeing lights does not mean that there is no light. Also, not hearing sounds and voices does not mean that there is no sound or voice. It means that they are either much lower or higher than the acceptable seeing and hearing range. We all may know about the human seeing and hearing range of frequencies. Regardless of the age of a human, in general, we are able to detect and *hear* sounds in a frequency range from about 20 Hz to 20000 Hz and *see* the frequencies between 4.29×10^{14} Hz (frequency of red light) and 7.50×10^{14} Hz (frequency of violet light)—the frequencies of visible lights in the electromagnetic spectrum (Walker, 2002; Hawkes et al., 2014). We are not able to see lights and hear the sounds above or below these ranges; however, they exist. In this case, not being seen should not be perceived as nonexistence. It has been a long time, over centuries, that females' voices and lights (of their abilities, skills, even existences) have been not heard and not seen properly in some fields of education and careers like physics (Barad, 2007). I believe that females in STEM might have not spoken up loud enough to be heard and seen in the fields or it has been beyond the fields' hearing and seeing range as there are so many highly resonated cases and voices with regards to females' underrepresentation in the fields of physics and STEM, like Karen Barad and Donna Haraway. The point lies here that there is a longstanding voice and light, which needs to be heard and seen properly.

Possibly, we need to apply changes on the conditions to see differences while creating a pattern which would illustrate the power of light. In the light of the Sun, the Moon is not seen, as its concern is the reflection of the sunlight and not itself. It dazzles in the darkness of the night, though it seems less than the Sun in the day. Darkness sometimes may cause a better scene for seeing and hearing things. However, observations with *consciousness* and *knowledge* result in an exploration. "Galileo thought comets were an optical illusion," (Dillard, 1974, p. 25) whereas they existed and were a reality. This was Galileo's assumption, not the truth, and did not change the *reality* and anything concerning their existence except providing an opportunity for others' explorations and improvements.

In brief, my experiences, the impacts of gender inequality and inequity in STEM-related occupations, women's underrepresentation in educational leadership positions, besides inspiration from Annie Dillard's and Karen Barad's perspectives, prompted me to explore, examine, and perceive new ways of seeing and looking at the issues through the lens of physical science and *light* phenomena. It is significant that how seeing the truth and existence, perceiving the diversity, and admitting a phenomenon pertain to the cultural beliefs, norms, values, and other factors. It truly depends on how we perceive and conceive matters. We—female and male leaders, administrators, educators, teachers, students, and parents—have to first change our ways of seeing and looking at a woman, and then attempt to resolve the gender parity issues and change the prevailing gender dynamics in different classes, careers and positions in STEM (Rosser, 1995). Moreover, as we have not yet succeeded in erasing this gender disparity in the 21st century, which had been predicted and stressed by Sue Rosser in 1995 and Karen Barad in 2007, "it could be that we are not seeing and [hearing] something" (Dillard, 1974, p. 25).

4.3. Initiation: scanning, detecting, and planning for the gender gap in STEM

We have not yet succeeded in erasing the gender gap to properly see differences in the era of the Fourth Industrial Revolution in the 21st century. Even though artificial Intelligence and robots are now part of our lives, we are still seeing and hearing the conventional wisdom and negative stereotypes that males are better than females in science and math (Hussénius, 2020). It is problematic that females are underrepresented in physical science (National Science Foundation [NSF], 2017; WEF, 2021b; Ceci et al., 2014), technology, engineering, and mathematics (STEM) both in academic and career fields (Robnett & John, 2020; Ceci et al., 2014). Furthermore, it is significant that diversity is very important for the future of education as well as the economy (Milner-Bolotin, 2015; Ceci et al., 2014; Sandberg, 2013). According to the American Association of University Women (AAUW) (2015) and National Science Foundation (NSF) (2016), girls and women are underrepresented in STEM academic fields as well as the workforce in STEM careers (Robnett & John, 2020, p. 231; WEF, 2021b; Ceci et al., 2014). Physics, of all the sciences, still has the lowest representation of girls and women and the highest rate of gender disparity and inequity in STEM education (Hussénius, 2020; Francis et al., 2017; National Science Foundation [NSF], 2017; Kahn & Ginther, 2017; Archer et al., 2017). In short, I problematize the ongoing existence of a previously problematized issue (deep-rooted) in STEM.

Moreover, this issue is not limited to girls' and women's participation and engagement in this field and discipline. Studies reveal that adolescents do not continue their studies in STEM and believe that these subjects and fields "are not being for them" (Francis et al., 2017; Archer et al., 2012; Brown et al., 2008; Hutchinson & Bentley, 2011; Institute of Mechanical Engineers, 2010; Larson, 2014; Lewis et al., 2009; Tripney et al., 2010; Hyde & Lindberg, 2007). For instance, they are reluctant to get involved and participate in subjects like advanced mathematics and physics courses in high school (Kahn & Ginther, 2017; Archer et al., 2017). The consequences and implications are even worse in the field of physics (Archer et al., 2017). Governments and educational institutions are subsequently concerned about a growing gender gap in STEM skills, particularly in the sectors of physics, as argued by Francis et al. (2017). I emphasize and echo that this gap may have begun to open with sexism at the student's early education and secondary school. Furthermore, it is significant that students' experience of sexism has a negative impact on their academic outcomes and achievement (Robnett & John, 2020). The only way to see progress and increase the presence of females in this field is not only to disrupt "prevalent constructions of the physical sciences as a masculine and 'hard' domain," but also to provide females with more opportunities for participation and accessibility to these subjects and related careers (Francis et al., 2017, p. 156-157). As I strongly believe and emphasize in this study, these opportunities should be initiated and provided at an earlier age of learning for girls, for example, from the last years of elementary school education, around grade 7 (Science, Technology and Innovation Council, 2015; CCA, 2015; DeCoito, 2016, 2015a, 2015b; Xu et al., 2015; NSF, 2020; Amgen Canada and Let's Talk Science, 2014, 2019).

4.3.1. Culture of Valuing Masculinity in Physics

Results of some studies demonstrate that "girls' and women's underrepresentation in STEM fields cannot be attributed to gender differences in STEM ability or achievement" (Robnett & John, 2020, p. 231, Hyde & Lindberg, 2007). However, Hussénius (2020) argues that women are being excluded from the fields where practitioners value male innate abilities and believe that women are not as capable. They believe that "men have a higher degree of specific innate talent," which women do not possess (Hussénius, 2020, p. 573). These kinds of ideas are being manifested in some disciplines like physics, mathematics, engineering, computer science, and even philosophy (Hussénius, 2020; Kahn & Ginther, 2017). However, the male-dominated environment of physics is a vanguard for all the aforementioned disciplines. For many years, feminist philosophers have critiqued this structural gap in science and explicitly relate it to masculine culture and power (Stengers, 2018; Barad, 2007; Rosser, 1995). The less frequent participation of youths, women's exclusion, and the marginalization of female students of colour in the physics field have created a specific male-characteristic dominant environment and discipline in science.

4.3.2. Relationship between Gender Difference in Problem Solving and Physics Learning

According to a meta-analysis of studies of gender differences in each literacy (verbal ability), numeracy (mathematical ability) and problem-solving (spatial abilities) areas, there are either no gender differences or girls perform better “in all areas except problem solving beginning in the high school years” (Hyde & Lindberg, 2007, p. 22). In other words, there is a small gender difference demonstrating boys outperform girls in problem solving at the high-school level and higher, which is also confirmed by the results from PISA (Program for International Student Assessment) 2018 across OECD (Organization for Economic Cooperation and Development) countries and economies, on average. It means that girls have a lower ability, which “involves extending knowledge or applying it to new situations,” which “is essential to success in occupations in engineering and the sciences” (p. 22). Moreover, it is important that physics and chemistry are the subjects in which students learn and practise problem solving skills at the high-school level (Hyde & Lindberg, 2007). As this gender difference in problem solving does not happen at earlier ages, and students are free to select their courses in high school, all this demonstrates why the results of gender differences in problem solving have favoured boys in the high school years.

Boy adolescents are more interested in taking physics than girls, who are more absorbed in biology and chemistry subjects (Kahn & Ginther, 2017; Hyde & Lindberg, 2007). It means boys, through their participation in physical science, practise and develop their problem-solving skills while girls do not. There is a mutual relationship between gender difference in problem solving and the girls’ tendency to participate in science, especially physics, in high school. The less participation by girls in physical and mathematical sciences, the more gender disparity in problem-solving ability as this skill is predominantly being learned and practised in STEM (Martín-Páez et al., 2019; Schwab, 2016; English, 2016; Beers, 2011). It is like a closed loop for girls. For less problem-solving ability, there is less success in engineering and mathematical science fields and careers which results in less adequate role models for other young female students and high schoolers. This might be one of the reasons why mathematical science and engineering have become the fields in which women are seriously underrepresented, from the points of view of Hyde & Lindberg (2007). Therefore, from my perspective, providing girls with opportunities to learn physics at early ages might help improve their problem-solving ability.

4.3.3. Looking at the Issue from a Different Perspective

If we look at the issue from another angle, we realize that girls and boys seem to develop their cognitive abilities, like verbal abilities and mathematical performances, by attending kindergarten/school from age five, on average. It shows that girls and boys may initiate their learning related to verbal and arithmetical skills at earlier ages; thus, they are granted a longer time—from elementary to high school—to familiarize themselves, learn, practise, and develop their abilities and self-confidence in these two cognitive skills. However, for physics, students' content learning and teachers' actual teaching are formally initiated at the high-school level, and more focussed teaching and learning occurs in the last two years of high school. From my point of view, the actual reason for the gender difference in problem-solving ability in high school and the lower tendency of girls to choose science, specifically physics, is related to girls' self-confidence (AAUW, 2010), the time of initiation of physics courses, and also the length of available years for students' content learning, practising and developing an adequate interest and wisdom in this field of science.

4.3.4. STEM Abilities of Males and Females

According to the National Science Board, from 2006 to 2012, female students in comparison with male students have the highest on-time graduation rates of US public schools. OECD Education Gender Ambassador and Directorate for Education and Skills, Marta Encinas-Martin (2020) states that women nowadays achieve higher levels of education than men in most countries in the world. However, their employment chances are less than that of men, as well as their wages (Barker, 2018; Moyser, 2017).

In addition, in 64 of the 79 OECD countries and economies that participated in PISA 2018, boys expressed more positive attitudes regarding competition than girls did, indicating that girls are less attracted to compete in STEM. Moreover, the results of the 2018 PISA in reading and mathematics assessments demonstrate that girls score 30 points higher than boys and two points higher in science assessment (OECD, 2019a). On the one hand, OECD (2019b) reveals that girls outperform boys in science in 19 PISA-participating countries and economies while boys outperform girls in 65 countries and economies and score higher than girls in science. On the other hand, AAUW (2010) reveals that girls achieve higher credits and higher points in math and science on average (Robnett & John, 2020). Thus, boys' and girls' STEM abilities and their academic achievement are not the only factors to explain the gender gap in STEM fields. As such, the conventional wisdom that boys are able to distinctively perform better than girls in science is not accredited and valued. Why indeed then are girls and women underrepresented in science, technology, engineering and mathematics (STEM) academic fields and careers?

4.3.5. Tracing History and Detecting Sexism

There are many examples in the world of women who have encountered sexism in the fields of STEM (Robnett & John, 2020). Most of these kinds of experiences have not been heard and noticed, while some of them, like the frustrating lived experiences of Jocelyn Bell Burnell (astrophysicist), Lise Meitner (physicist), Chien-Shiung Wue (physicist), and Esther Lederberg (microbiologist), have been proved and reflected throughout history. For instance, I refer to one of these dark experiences and challenges female scientists have faced in the male-dominated milieu. Rosalind Franklin was a woman whose scientific contributions have been extremely underplayed; whose work revolutionized biology and medicine; and who fought sexism in science (Gibbons, 2012; Selya, 2003; Elkin, 2003; Shapley, 1975). She was the actual discoverer of the structure of DNA, one of the most important scientific achievements in the last century (Gibbons, 2012; Selya, 2003; Shapley, 1975). However, two male scientists, James Watson and Francis Crick, won the Noble Prize for the double Helix (Gibbons, 2012; Selya, 2003). Franklin wanted to be a scientist ever since she was a teenager, which was not a common or easy career path for girls at that time. With all the barriers, she strived and shined at science and won a scholarship to Cambridge to study chemistry and to earn a PhD in that field of science. She continued her research, which led her to make a better gas mask during World War II.

Afterwards, she initiated working and studying the structure of DNA utilizing X-ray (Barad, 2007; Elkin, 2003). About 70 years ago, Franklin was segregated from her peers and colleagues because of the male-dominated culture in science (Gibbons, 2012; Elkin, 2003). As such, during her work at the lab, she conflicted with one of her colleagues, Maurice Wilkins, who was considering her as his assistant. With all these difficulties and challenges, she enthusiastically continued working on the DNA's structure and took the most famous X-ray image of DNA, Photo 51, after spending hundreds of hours of work with X-ray and a year calculating and analyzing the images (Gibbons, 2012; Elkin, 2003; Selya, 2003; Shapley, 1975).

On the other side, at the same time, Watson, an American biologist, and Crick, a British physicist, were also working on the structure of DNA (Gibbons, 2012; Elkin, 2003). Wilkins, who had clashed with Franklin and also was working with her in the X-ray lab without her permission, unscrupulously gave Photo 51 to Watson and Crick (Gibbons, 2012). They did a quick analysis and calculations of Franklin's data and image and came up with the structure of DNA (Gibbons, 2012; Elkin, 2003) then promptly attempted to publish it before Franklin. At the same time, Franklin also finished her work and reached the same result and structure of DNA (Gibbons, 2012; Elkin, 2003; Selya, 2003; Sayre, 1975; Shapley, 1975) and endeavoured to publish the findings. However, the results of her hard work came after Watson and Crick's publication (Gibbons, 2012; Elkin, 2003). It seemed, therefore, as if Franklin's paper was to further prove the discovery the two male scientists claimed to be theirs, when in fact Franklin was the one who had put her life and future on the line to follow her desire to further discover the beautiful art of DNA.

Throughout the process of discovering one of the most fundamental aspects of a human—DNA—Franklin risked her life by working with multiple hazardous chemicals and exposing herself to X-rays in hopes of furthering her knowledge and fulfilling her own desires (Elkin, 2003). In her mind, these risks would have all been worthwhile if she had received the recognition she deserved. However, her work was stolen from her, and tragically all the risks she had taken resulted in her developing cancer and dying at only 37 years old. Because she was a woman, she was not recognized as a scientist who discovered the structure of DNA.

Rosalind Franklin was a female scientist in the field of biology and medicine about 70 years ago. My focus is on the field of physics in science, not biology. You might ask why I have not chosen any recent example from the field of physics since the depth of the issue cannot be described by itself. As I mentioned in the section on the problem statements, women are now overrepresented in the field of biology and medicine (Hsieh et al., 2019; National Science Foundation [NSF], 2017; Ceci et al., 2014) and are *still underrepresented* in the field of physics (Natural Sciences and Engineering Research Council of Canada, 2010; American Physical Society, 2015; Barad, 2007; Baram-Tsabari & Yarden, 2008; Kahn & Ginther, 2017; WEF, 2021b). If women in the field of biology had such experiences 70 years ago while their issue of underrepresentation in this field has been now resolved, you could imagine what women's experiences could have been in the field of physics in which they are *still underrepresented* in 2021. Do we still (in the 21st century) have females in the field of physics who are being frustrated and having experiences like Franklin in the 20th century?

Undoubtedly, living, learning, studying, and working in a male-dominated environment has its own complications, challenges and consequences. Most women leave the field because of the male-dominated culture (Barad, 2007; Hussénius, 2020); however, some like Donna Strickland stay and persist and become the third woman ever to win the Noble prize in the field of physics. Of course, being excluded and marginalized in a field either academically or professionally in which only some dominant groups are privileged is not encouraging for women and young generations.

4.3.6. Definition of Privilege

As part of an in-depth investigation, I first attempted to understand the meaning of *privilege*. In everyday usage, "privilege means to be lucky, to have fortunate opportunity and to benefit from this luck and opportunity" (Sensoy & DiAngelo, 2017, p. 104). However, in a critical social justice and academic context, these positive definitions are explicitly converted to social, cultural, institutional, educational, and political "protections," "rights," and "advantages" that some dominant groups—who have occupied the positions of power—have and others do not. Therefore, some people subsequently are being marginalized, segregated, minoritized, discriminated against, and finally oppressed, such as females and people with different abilities. Privileges and advantages for the male-dominant group, which were denied to women, create gaps and issues related to gender and class like gender inequity and women's underrepresentation in societies. Moreover, it is significant that our assessment, evaluation, participation, and collaboration need to be independent of gender, class, and race. In this way, we might be able to convert the meaning of *privilege* to its original definition and conceive it as a positive product of “fortune, luck, or happenstance” for everyone in all social, educational, and cultural contexts.

Furthermore, privilege is something dynamic rather than static, according to a discussion in November 2020 by Professor Sean Blenkinsop. If it is dynamic, there would be ways in which it occurs and involves some people having more access to certain things that everyone values, for instance, the right to speak and the right to participate. Therefore, if we assume that privilege is dynamic, we can actually change the rules within that space and environment to make the privilege less in a different setting. For example, not everyone has the privilege to participate in some particular activities and employment opportunities. Even if they participate, they could be tacitly and subtly ignored as there are other privileged ones with higher priorities like the male-privileged environment in STEM. However, according to the Canadian Association of Physicists, the Natural Sciences and Engineering Research Council (NSERC), and scholars, there are some changes applied on the dynamic structure of privilege in the gendered science to grant higher priority and opportunity to more women and girls in the fields of STEM as the goal is to close the gender gap in Canada (Predoi-Cross, 2019; Xu et al., 2015).

4.3.7. Definition of Marginalization

Second, I delineate “marginalization,” which was used for the first time in 1968 when men, for the first time, travelled with a spacecraft, Apollo 8, to orbit the Moon and see Earth from Space, while women on Earth were fighting for their rights. I provide a brief description of the related factors and reasons that cause marginalization. The On-line Etymology Dictionary states that the word “margin” has a Latin root in the word “margo” which means “edge” and “little effect or importance.” According to Merriam-Webster (n.d.), “to marginalize” means “to relegate to an unimportant or powerless position within a society or group.” Moreover, this resource utilizes a very relevant example to our concern and the topic of this paper that demonstrates the meaning of marginalizing women: “We are protesting policies that marginalize women (Merriam-Webster, n.d.).” It is significant that “to marginalize” is an active verb; it is something that is done by someone to someone else” (Dei & Rummens, 2010, p. 50). Therefore, this is a binary process and involves two sides—on one side is the person who is being marginalized and on the other side the person who marginalizes; together they shape the culture of *marginalization*.

In this binary process, the marginalized side enters into a process of educational, social, and economic "de-valuation that serves to justify disproportional access to scarce societal, [educational and professional] resources," advantages, rights, and protections (p. 50). For instance, considering the marginalized female students,

> It is educators, teachers, along with other adults and peers, who—through their identifications, their "seeing" and "not-seeing", their [educational, professional, and] social inclusion or exclusion—relegate certain individuals and [educational, professional, and] social groups toward the edge of the [educational, professional, and] societal boundary, away from the core of import. (Dei & Rummens, 2010, p. 50)

Here, female students are subsequently considered on one side and the others with their own various ways of "seeing" and their own agency on the other side. This dualism brings the marginalized female students an "experience of [educational, professional, and] social devaluation, invisibility, silencing, unresponsiveness, and inaction" (p. 50). A marginalized female is a female whose educational, professional, social, and economic position is not properly valued and understood; whose life challenges and circumstances are not amply known and not fairly considered; whose educational, professional, social, and economic needs have been left unfulfilled in some societies; whose promise is not respectfully recognized; whose complaint is deliberately ignored; and whose rights come after males.

4.3.8. My Lived Experiences in the Field of Science, Particularly Physics

In this section, I refer to the regressive, progressive, and analytical moments in the method of *currere*. I return "to the past, to capture it as it was, and as it hovers over the present" (Pinar, 2004, p. 36; Pinar & Grumet, 1976, p. 55). I imagine possible futures and *examine both past and present* in the analytical stage of *currere*.

> I see that there is a coherence. Not necessarily a logical one, but a lived one, a felt one. The point of coherence is the biography as it is lived … The predominant [question] is: what has been and what is now the nature of my educational experience? (Pinar & Grumet, 1976, p. 52; quoted in Pinar et al., 1995, p. 520)

As I, as a female educator, am interested in exploring more regarding gender parity and disparity issues in STEM education, I move a gender lens over my own lived experiences. I attempt to shed light on the issues and resonate with some incidents with regards to participation, preferences, and interests in my life in the field of science. It is significant that “preferences are also likely to reflect barriers to female involvement such as gender stereotypes, workplace culture, lack of role models and risk aversion” (Barker, 2018, p. 29). Therefore, I reflect on the impacts of *gender stereotypes, lack of role models*, *culture of workplace and educational environment*, and the *risks* to my preferences and experiences, not only in education but also in work. Moreover, there are other factors like the impact of parental and family engagement and encouragement on adolescents’ education which needs to be considered in the current literature by educators, researchers, and even administrators (Green et al., 2007; Hango, 2007; Harris & Goodall, 2008; Amgen Canada and Let’s Talk Science, 2015; Milner-Bolotin & Marotto, 2018). Thus, I point out and stress the importance of *parental engagement* with children’s formal and informal science, engineering, and mathematics education as the results of researches demonstrate the benefits of parental engagement with your child’s education (Barton et al., 2004; Green et al., 2007; Harris & Goodall, 2008; Kaya & Lundeen, 2010; Amgen Canada and Let's Talk Science, 2015; Perera, 2014; Milner-Bolotin & Marotto, 2018).

As I believe that self-reflection may result in exploration and a better understanding of one’s circumstances, I refer to my lived experiences since learning general science in my middle school years in Iran. At the time of my education, grades 6, 7, and 8 (according to the Canadian educational system) were counted as three middle school years in the Iranian educational system. During these three years, we were introduced to more general science content after our elementary school years. The content was a mix of various topics and concepts from different disciplines of the natural and physical sciences such as physics, chemistry, and biology. I was not able to recognize which topic was in which discipline; however, I was able to discern that I was attracted to and more interested in learning some particular topics and lessons than others.

The influential factors on my interests were better understood after years of teaching and studying in the field of physics and education. My father, a civil engineer and former mathematics teacher, with exceptional knowledge in mathematics, was always passionate about teaching and transferring his knowledge not only to me but also to others, regardless of how busy he was. Later on, I realized why I was interested in some concepts and lessons but not in others. The effects of parents, family members, and family friends with STEM backgrounds on a youth's interest in the mathematical and physical sciences is significant (Milner-Bolotin & Marotto, 2018; Archer et al., 2017; Amgen Canada and Let's Talk Science, 2015; Barton et al., 2004; Green et al., 2007; Harris & Goodall, 2008). However, maybe something can be explored about teachers here, too, and the amount of encouragement and attention I received from them; it is the other important factor associated with a student's interest (Tawbush et al., 2020; Archer et al., 2017; National Research Council, 2011). Consequently, my learning experiences resulted in loving and enjoying anything related to math or had mathematical logic and roots.

By the time I entered high school (equivalent to grade 9 in the Canadian educational system), physics, chemistry, and biology were introduced to us as the mandatory subjects. In the first year, we had the opportunity to learn all three subjects together and had a taste of each. We were expected to choose our major and field of study at the end of the first year for the rest of our education, not only in high school but also for post-secondary education. There were three options and majors: 1- Mathematics and Physics (mathematical sciences), 2- Biology and natural sciences, 3- Humanities and Art (social sciences). It was important as not all three majors were being offered at all schools.

I grew up in a family whose education was mostly in the field of civil engineering—my father, my brothers, my uncle, and my cousins. Mathematics had a respect and special place between us and still has. Scholars and educators argue how participating in the post-16 mathematical and physical sciences are strongly valued and encouraged by cultivating "a science-rich family habitus" (Archer et al., 2017, p. 102). I was the first person in the family who chose mathematics and physics majors in high school. By choosing these majors, I felt that I was stepping into a masculine zone and sovereignty. It gave me a sense of power but not in the male-dominated milieu. This feeling was then transformed into a belief when I did not see any female physics teachers until the end of my high school education. I was getting used to it; even I had not noticed that this is not normal. Not having a female physics teacher—a proper role model—during high school was not something unexpected and strange for me in Iran. At the end of high school, my father encouraged me to continue my post-secondary education in the field of civil engineering or architectural engineering as he was a founder, owner and manager of a consultant engineering company and wished to involve his children in the company. However, with my enthusiasm for a physics major, I had already made up my mind. In grade 10, my male physics teacher encouraged me and profoundly motivated me to pursue my studies in the field of physics.

By initiating my undergraduate studies in the field of physics (physics major) after passing the Iranian University Entrance Exam, again, I felt a sense of power. I felt power entering a *hard male-dominated* field as a female; and felt power learning a subject considered difficult by many students, particularly girls, and that requires them “to be highly ‘exceptional’” in order to “possibilize a physics identity” (Archer et al., 2017, p. 89). At the beginning of the program, I was happy and satisfied though there were few girls in some of the courses; we were like strangers there—our voices, our presence, our requests, and our concerns all were considered differently. Mathematical law was contradicted here. Every three girls’ presence and voices were equal to one boy’s voice—1 boy = 3 girls, like 1 kilogram = 1000 grams—though both are human beings. What kind of system of measurement is this? How was this being measured? What were the units of measurement there? Which one was the larger unit, boy or girl? *Is gender a measurement unit for a human being?*

I am not sure. What I know is that we, my female peers and I, were less than a boy—devalued. Our perspectives, our opinions, our knowledge, and even our work were counted less than boys’—silenced. The way that we were being treated, valued, and considered in the program was different from the boys—discriminated. I was studying and living as a student who was not going to be allowed to have any authority or even to be counted as a real and permanent member of that community for a long time—marginalized. I was a temporary member and student in the male-dominated spaces and dialogues. No one would take us—females—seriously in that environment. It was like I had been permitted to enter the male-dominated zone to just quietly learn worthwhile knowledge without any autonomy, power, and authority over my learning. Though at that time I had never thought of these factors, all my feelings of power were only internal and seemed unreal. Entering and being in that sovereignty of males counted as a lot in itself—granting and holding a physics identity. It was like I had been privileged by my presence and entrance to the masculine domain, and that should be enough. Finally, in

2002, I completed my studies and graduated with a Bachelor's degree in Applied Physics – Atomic, where, *again*, *I had no female professors or instructors as role models during my whole journey.*

On the other hand, I was being seen differently in the female milieu. In "The Ideal of the Educated Person," Roland Martin argues that there are gender differences by studying Peters's ideal of the educated person by considering male and female traits. I am thrilled by how she discusses the issue:

> Imagine a woman who is analytical and critical, whose intellectual curiosity is strong, who cares about the canons of science and mathematics. How is she described? "She thinks like a man," it is said. To be sure, this is considered by some to be the highest accolade. Still, a woman who is said to think like a man is being judged to be masculine, and since we take masculinity and femininity to lie at opposite ends of a single continuum, she is thereby being judged to be lacking in femininity… (Roland Martin, 1981, p. 103)

We were being seen, treated, perceived, and evaluated by having imposed on us "a masculine mold." We were all female marginalized strangers, from all aspects, who were striving to define and demonstrate ourselves in the male influenced and dominated environment. However, again, I was feeling power by overcoming a perception that everyone was telling me—"You cannot. It is a hard major to study. It is a masculine field." I am happy that I could fulfill and follow my *passion*, which I strongly believe is an important factor for self-realization, self-affirmation, self-understanding, self-criticism, self-mobilization, and achievement as accentuated by Pinar (2004, 2019).

Nonetheless, I am not happy that I let the pressures and impacts of the gender stereotypes (boys performing better in mathematical sciences), workplace culture (men doing jobs which women cannot), patriarchal environment (men's perspective is right and should be regarded first), lack of role models (no female physics teacher at high school and no female instructor at university level), and risk aversion stop me from continuing my graduate studies in the field of physics. I am not happy about becoming exhausted from *competing* with males in this field. I am not happy when I see my students' *preferences* are not physics. I am not happy when I am not able to absorb and keep more students in physics as the educational and societal system advertise masculinity over femininity. I am not happy when I see statistics and results of assessment tests of students and then their participation in physics. I am not happy when I see that the majority of physics teachers are male. Even when it comes to scholarly study in the field of physics, the proportion of accepted articles written by women are fewer than for men. For example, men have 82.4% acceptance and women have 17.1% in IOP Science, Physics Education journal (IOP Science, 2021). Indeed, I will be delighted when I see greater participation and representation of girls and women in the field of physics.

4.3.9. Scattering Techniques in Physics

In physics, there is a method called *Scattering* techniques. Many areas of research in physics have applied this technique to investigate the structure of an object and its atoms like “investigations of the distribution of electrons in atoms and the magnetic properties of nuclei” (Hawkes et al., 2014, p. 821). This technique helped Ernest Rutherford explore not only the existence of the nucleus but also the size of the nucleus in an atom at the start of the 20th century (Walker, 2002; Hawkes et al., 2014). In this technique, charged particles pass through an object and hit a zinc sulphide screen that gives out tiny sparks of light after the particles hit it. The pattern created by the sparks on the screen helps the investigator to analyze the results and infer some information about the structure of the object and its properties. Some particles go straight, meaning that their way was clear of obstacles or there was nothing in their way to block the path or the travel (empty space). Some particles are deflected or completely bounce off, meaning that there was something either to block their way or to force them to change the direction of travel (full and occupied spaces in which the other particles create an opposite force). Depending on the size of the barrier and the force, the amount of deflection and rebound alters. As such, there is a significant relationship between the size of the barrier and the size of deflection or bounce of the particles. In brief, so much information can be inferred from the scattering experiment in science to understand the structures and behaviours of the particles in atoms and eventually in objects.

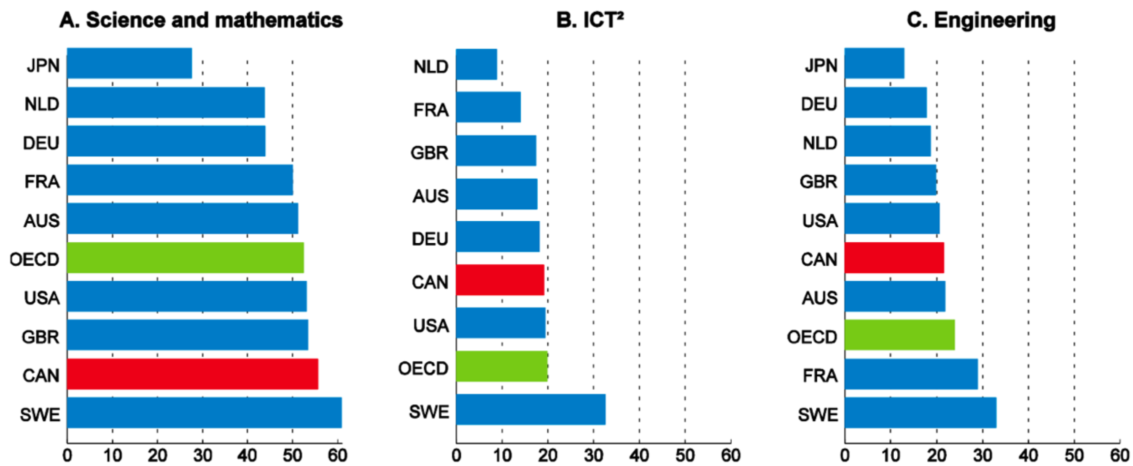
Relating to some extent to the scattering technique, it is concerning that the rate of students’ interest and engagement, particularly girls, in math-intensive STEM fields noticeably decreases in the higher grades in high schools and higher levels of education and subsequently in future careers too (Kahn & Ginther, 2017; Francis et al., 2017; Archer et al., 2012; Brown et al., 2008; Hutchinson & Bentley, 2011; Institute of Mechanical Engineers, 2010; Larson, 2014; Lewis et al., 2009; Tripney et al., 2010;

Hyde & Lindberg, 2007). This issue creates a huge gender gap in the fields (Hussénius, 2020; Francis et al., 2017; AAUW, 2010) and economic concerns in the future labour market (Kahn & Ginther, 2017; Encinas-Martin, 2020; Science, Technology and Innovation Council, 2015; CCA, 2015; DeCoito, 2016, 2015a; WEF, 2021b). In other words, the results of studies demonstrate that students' preferences for physical and mathematical sciences are being changed or deflected due to various factors and reasons (maybe barriers) in STEM fields. As such, it illustrates a kind of *scattering pattern* of students' participation and attendance in the field of physics, which is a mathematical science in STEM, for example. I argue and believe how information about the structure of this field of science and the existing barriers can be inferred from the scattering patterns created by students' disengagement and their destructive experiences in the field of physics. To sum up, this technique as a metaphor helps us recognize not only the existence of (male-dominated and male-related) barriers but also the strength and size of the obstructions (their domination and dominated issues) in the structure of this field of science.

4.3.10. Females' Participation in STEM and OECD Results in Canada

PISA not only evaluates students' abilities and performances in mathematics literacy, reading literacy, and science literacy, as well as in problem solving skills, but also collects valuable data on gender and socioeconomic backgrounds related to the differences of students' performance according to the students' characteristics and educational institutions (OECD, 2010a). Since 2015, science was a minor domain in PISA, with more limited analyses of data (NCES, 2020). However, PISA 2025 and its assessment framework will be developed by a group of scientists and international science education experts who will concentrate on science as a major domain (OECD, 2020a), providing us with more detailed information and data on students' science participation and engagement.

I refer to some OECD statistics results and analyses to reflect the current progress in erasing gender disparity in STEM. For instance, Canada, between OECD countries and economies, with 45% female graduates in science, math, and computing, has succeeded in decreasing the gender gap and demonstrated gender equality in STEM education in the world (Barker, 2018; OECD, 2017).



1. Science, technology, engineering and mathematics.
2. Information and communication technologies.
Source: OECD (2017), *Education at a Glance database*.

Figure 4.1 Canada's gender equality position in STEM bachelor degree's graduates, Female shares in per cent, 2015 data (Adapted from Barker, 2018, p. 29; OECD, 2017)

This figure illustrates the gender-equality position in science, mathematics, technology, and engineering bachelor-level graduates in Canada in 2015. Canada has exceeded the OECD average in science and mathematics but is less than the OECD average in information and communication technologies and engineering. As such, still, the number of girls and women is low in male-dominated fields like mathematical sciences, physics, engineering, and computing in comparison with the OECD average (Barker, 2018; Kahn & Ginther, 2017; Archer et al., 2017; OECD, 2016). The results of studies reveal that women, not only in Canada but also in the United States, are less likely than men to enter into physical science and computer science careers after completing their education at the post-secondary level. And they are much more likely to leave these professions for various reasons (Barker, 2018; National Science Foundation [NSF], 2017; Amgen Canada and Let's Talk Science, 2014, 2015, 2019; NSF, 2020; NSERC, 2010). "Lack of mentoring and networks or discrimination by managers and co-workers" are some of the reasons for their withdrawal and exit from these fields of science and engineering, as argued by Hunt (2016).

4.3.11. Removing Barriers to Women's Participation in STEM in Canada

Canada has launched different programs and projects to promote greater participation of women in STEM since 2015, such as the following: *NSERC Student Ambassadors program* for engaging adolescences to mentor other young Canadians in STEM outreach activities (NSERC, 2021); the *NSERC Young Innovators program* for national and international participations in STEM-related competitions (NSERC, 2021); the *Student Work-Integrated Learning Program* to support and assist post-secondary students in STEM (Barker, 2018; NSERC, 2021); the *PromoScience Program* to provide funds to organizations which support K-12 students by providing them with opportunities to participate, engage, and develop skills and knowledge in STEM (NSERC, 2021); and the *ChooseScience* digital campaign which provides parents and teachers with resources to encourage young women towards STEM careers (Barker, 2018).

Barker (2018) states that "removing these barriers is important to increase the inclusiveness of opportunity to benefit from economic growth and to offer more flexibility in work" for women and girls (p. 31). In short, Canada actively attempts to remove obstacles and improve the participation of young women and girls in STEM education and careers to "enhance the diversity of talented and innovative people who fuel our future" (Government of Canada, 2018, p. 13) and economics (Science, Technology and Innovation Council, 2015; CCA, 2015).

In fact, I draw from my twenty years' experience of teaching physics to national and international students at the high-school level. I also draw on my experience of learning physics at high school and at an undergraduate level in Iran, being the mother of a female high schooler in Canada, and also designing a science curriculum in an extracurricular and enrichment science program in British Columbia. These are all that acknowledge my identity and integrity in teaching and learning physics. The importance of teacher's identity and integrity has been explicitly argued by scholars in education (Palmer, 1998; MacKinnon & Moerman, 2016). Therefore, *I believe that youths, particularly girls, can and may initiate their physics learning at about grade 7 as they are mainly interested in learning (mathematical) science at their early ages (*Bennett & Hogarth, 2009; Hsieh et al., 2019; Amgen Canada and Let's Talk Science, 2014;

DeCoito, 2016, 2015a). This initiation should be directly under the name of physics, not a general science, as the difference matters (Hsieh et al., 2019).

Finally, what I state here is what I have experienced and learned from and with my young students' formal physics learning in my classrooms in an international public school in Iran and consistently observed their learning and future achievement for seven consecutive years from grades 7 to 12 as their physics teacher. The students were international students from different countries with various sociodemographic factors. In addition, students' rates of participation in all levels besides my perceived outcomes (as a director and instructor of SCP program) of an extracurricular and enrichment after-school science program (SCP) for adolescents in British Columbia, Canada, reveal that young adolescents, particularly females, are able and interested in initiating their physics learning from grade 6 as well as evolving their knowledge to quantum physics when they are in grades 8, 9, and 10. For obtaining evidence and data about this particular science program, further studies are desired as is mentioned in Chapter 5 at the end of this thesis. However, this is not the focus of this current study.

4.4. Second Important Conclusion for New Initiations

The main goal of this chapter was to shed light on a problem that was detected and problematized in science a long time ago; however, it still exists. The purpose of this literature review is to argue and underline girls' and women's underrepresentation in STEM, not only in academic fields but also in professional careers (Barad, 2007, 1995; Robnett & John, 2020; Francis et al., 2017; Milner-Bolotin, 2015; Ceci, 2014; Sandberg, 2013; AAUW, 2010; WEF, 2020b, 2021b; NSERC, 2021; NSF, 2017). Women "who [are] not viewed and recognized as a true member of a science or technology community" (Hussénius, 2020, p. 573) are still being underrepresented in these domains (NSERC, 2021; Kuschel & et al., 2020; Francis et al., 2017; AAUW, 2010; WEF, 2021b; Robnett & John, 2020). Thus, women's exclusion in STEM, specifically in the physics fields and careers, has resulted in a huge gender gap in this area of science (Martín-Páez et al., 2019; Francis et al., 2017; AAUW, 2010; NSF, 2017; Kahn & Ginther, 2017; Archer et al., 2017) as mathematical and physical science is realized by many cultures and societies as a predominantly male domain (Hussénius, 2020; NSF, 2017; Kahn & Ginther, 2017; Archer et al., 2017; Francis et al., 2017). It is significant that the experience of marginalization and sexism affects not only female students' learning outcomes but also women’s representation (Robnett & John, 2020). This gender issue in physics and patriarchal structures of some cultures illustrate how particular contexts demand flexible and creative approaches towards women’s representation and inclusion. Furthermore, there are some undeniable barriers for females such as “gender stereotypes, workplace culture, lack of role models and risk aversion” (Barker, 2018, p. 29) which each has its own implications and impacts on girls’ and women’s participation, enrollment, and representation in mathematical science.

To support my perceptions and arguments, I have provided some data with regards to males’ and females’ participation and achievements in STEM and how male and female adolescents are reluctant to choose advanced mathematics and science courses in high school (OECD, 2016, 2019a, 2019b; Barker, 2018; Francis et al., 2017; Archer et al., 2012; Brown et al., 2008; Hutchinson & Bentley, 2011; Institute of Mechanical Engineers, 2010; Larson, 2014; Lewis et al., 2009; Tripney et al., 2010; Hyde & Lindberg, 2007). Girls and boys with different interests and competitive attitudes have different career preferences (Barker, 2018; Kahn & Ginther, 2017; Amgen Canada and Let’s Talk Science, 2014). For example, boys outperform girls in problem-solving skills, which are usually taught in physics and chemistry (Hyde & Lindberg, 2007). These are the subjects in which girls have less self-confidence and willingness to participate and compete in than boys (AAUW, 2010).

However, some studies reveal that there has been a slow pace of progress in shrinking the gender gap in the field of physics in high school, in academia, and in professions since the last century (Hussénius, 2020; Francis et al., 2017; NSERC, 2021). The results of researches indicate that the role of girls and women in STEM education has received increased attention across a number of disciplines in some countries in recent years (Barker, 2018). Canada is one of the OECD countries that has a high rate of representation of women in science and mathematics, by overcoming barriers to employment among women (Barker, 2018). We need an adequate role model for girls to inspire future women in science, *a female role model* (Weber, 2011). Therefore, not only do we need to focus on opportunities to improve outcomes for females who face barriers to social, educational, professional, and economic inclusion, but also the *hard masculine domain* of physical sciences must be disrupted (Milner-Bolotin, 2015; Barad, 2007; Ceci, 2014).

In this section, I step into the last stage of *currere*—"the moment of synthesis," "one of intense interiority"—where a "pedagogical political practice for the 21st century" is reflected (Pinar, 2004, p. 38). Francis et al. (2017) argue that "We need to find ways to work with young people to unpack these discourses in order to reflect critically on the status quo" (Francis et al., 2017, p. 172). Therefore, we—parents, teachers, administrators, and educators—need to help adolescents fulfill their potential and subsequently prepare for future careers and their role as 21st century citizens in a rapidly changing world by supporting their learning and engagement through science, technology, engineering and math (STEM). "Early … education reduces the barriers to further education and finding employment faced by children …" (Barker, 2018, p. 28). Scholars disclose that girls have shown interest in learning STEM at extracurricular and after-school science programs outside the formal and normal school science education (DeCoito, 2016; Gonsalves, 2013). Therefore, I strongly recommend that students be introduced to the subject of physics in grade 7, somewhere between grade 6 to 8, at an enrichment science program as the gender gap begins to open at earlier ages. Initiation of learning this subject at a younger age and in lower grades when they have shown more interest provides students with two opportunities: 1- Students become familiar with physics—mathematical science—besides mathematics, to gradually develop their understanding of this science under the mathematics' umbrella and improve the *girls' confidence* in this subject (AAUW, 2010); 2- Learning physics in a broader and vastly longer time, which decreases the pressure and difficulty of learning content in just the last two years of high school. Even in some current educational systems, these two years have shrunk to only two semesters, less than seven months.

Consequently, according to scientific institutes such as NSERC (2021), CCA (2015), and the Science, Technology and Innovation Council (2015), importance of STEM-based initiatives for young students, especially females, in Canada is manifest. Thus, I again stress that students' early involvement in learning physics content would promote girls' self-confidence in class, in school, in society, in life, and finally in their career. Acknowledging the challenge of such initiation, I suggest an extracurricular and enrichment after-school program with particular focus on physics content learning to increase and widen girls' participation and access to this subject at an early age, which might inspire and increase women's future involvement in science careers toward economic production and prosperity (Science, Technology and Innovation Council, 2015;

CCA, 2015; DeCoito, 2016, 2015a, 2015b; Xu et al., 2015; NSF, 2020; Amgen Canada and Let's Talk Science, 2019).

Chapter 5.

My Experiences: From Theory to Practice

5.1. Curriculum and Pedagogy

5.1.1. Practices and Lived Experiences During the COVID-19 Pandemic Since 2020

According to John Dewey (1902), in *The Child and the Curriculum*, students need a curriculum which "gives direction"; facilitates their engagement and learning; economizes efforts; prevents "useless wandering, and point[s] out the paths which lead most quickly and most certainly to a desired result" (Dewey, 1902, p. 27). In the meantime, curriculum "scientific contents […] should be reasonable and reasoned, and should practice in a system of ideas and actions that is coherent, valid, and at the reach of students" (Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 27). Moreover, students need a scientific curriculum which has been updated with their contemporary life (Tyler, 1949; Pinar, 2019). Therefore, *rethinking, redesigning and reconstructing* may be required in response to the needs for upgrading and *updating* scientific contents of the curriculum.

I refer to my own lived experiences—*practices*—in my work and study as an example to illustrate in thinking and design. I return to the past—regressive moments—that is, the moments when I initiated my work to develop and design the curriculum of the Science Circles Program (SCP) in 2020. I had to write the curriculum of the first two classes of Level 1 (before the time of the COVID-19 pandemic and before the rest had already been designed and written by other educators) and Level 2 (simultaneously with and during the COVID-19 pandemic). I initiated Level 1 with the regular topics and concepts of physics which would be at the start of any physics books or physics curriculum. I had no concern about the curriculum that I had to teach nor about my pedagogical approaches for teaching physics in my future classrooms since I was holding about twenty years of experience in this field, formally and informally.

As I was writing the curriculum of Level 2 and ending my first term of doctoral studies at SFU, I simultaneously heard news about strict lockdowns due to an outbreak of a virus from the city of Wuhan in China and in other parts of the world. It was at the beginning of the COVID-19 crisis. I not only aimed to write the assignments for the first courses of my doctoral studies at SFU but also to formally initiate my research and endeavour to devise and create the foundations of my doctoral thesis. Scholarly articles, books, news, forums, my personal experiences as well as the status quo (current happenings and circumstances) became the sources of my studies. It was important that my work as an instructor and my doctoral studies be tightly interwoven. I had to first conduct research in my studies and then apply it to my work. In brief, I had to temporarily pause writing the Level 2 physics curriculum for a while, at least until I understood something that could lead me in the right direction in my work as well as my studies. I sought to acquire a better understanding of the challenges and changing views as well as expectations of the near future.

My studies at the end of the first term of the doctoral program in the spring of 2020 resulted in my exploring some interesting outcomes, not only in the field of education and the future of education but also in the world. I was excited by my investigations regardless of the disagreement I received on my analyses and views. However, all these factors only enhanced my enthusiasm and motivated me to explore more and correspondingly move forward in that field. The results describe a huge shift and the crisis of COVID-19 as reshaping everything in education and around the world (Weissbourd et al., 2020; Schwab, 2016, 2020; Schleicher, 2020; Reimers & Schleicher, 2020). The results speak about a revolution and the emergence of AIs and robots as our collaborators (Schwab, 2016, 2017; Schwab & Davis, 2018; OECD, 2021b; Philbeck & Davis, 2019). I might have a collaborator or a virtual substitute that may change my role from a teacher to a facilitator in future education. As mentioned in chapter three and elsewhere, I explored the Fourth Industrial Revolution and its impacts on everything (Schwab & Davis, 2018; WEF, 2020c; Schwab, 2016, 2017, 2018, 2021; Schwab & Malleret, 2020; Reaves, 2019; Philbeck & Davis, 2019).

Due to the COVID-19 pandemic in March 2020, SFU cancelled all in-person classes. Students were required to leave the SFU campus and enter Zoom classes. Moreover, students around the world had to leave in-person classrooms and enter virtual classrooms for their safety and health concerns. In short, because of the challenges, students and instructors had to quickly initiate the use of technology and work with different online teaching and learning platforms. It was a time in which students and teachers were trying to connect and resume their learning and teaching processes.

It was the moment that I had to imagine the effects of the outcomes of my studies as well as the future of education—the progressive moments. It was the moment that I started thinking about my own physics classrooms and my pedagogical approaches for online learning and teaching though I was not sure how long these uncertain conditions would last. It was the moment that I had to return to myself and my lived experiences too—the regressive moments. I had to slow down, review, re-enter the past, analyze the present. I had to imagine the future to be able to understand the reality—the analytical moments—to mobilize myself, take immediate steps to develop and implement strategies and reconstruct a curriculum and pedagogy in the present, as argued by Pinar in his method of *currere* (2019). Although it was a time of uncertainty, I had to initiate working on the Level 2 curriculum of SCP.

My work for SCP was coordinated with the challenges and changes induced by the global pandemic (COVID-19) at a critical time in the 21st century. I explored and understood that I should design and develop a curriculum which should adapt to the Fourth Industrial Revolution, respond to the 21st century students' needs and their future careers, and possibly be pragmatically taught during the complicated time of the pandemic with virtual and online tools. It became the moment that I had to consider the curriculum and pedagogy together; the moment that I had to think of not only a new curriculum but also a new pedagogy for teaching physics, as the previous approaches were not very practical and useful in online teaching and learning or even adapted to the Fourth Industrial Revolution and the current changes in education.

I had to *rethink* and *redesign*, and even *learn* in this process. It was the moment that I had to apply Pinar's method of *currere*. I had to refer to my past experiences of teaching physics and being not only a teacher but also a student in physics classrooms (regressive moments) while imagining the future of teaching and learning physics online with digital devices and technology (progressive moments) and analyzing the present with its incidents, challenges, and changes (analytic moments). I was not alone there; all passionate and enthusiastic teachers around the world devoted their time and life to learn, to keep pace with the changes, to update, and to adapt themselves with new approaches in teaching during the pandemic (OECD, 2021b; Schleicher et al., 2021; Schleicher, 2020). Students had the same experiences too. It was important as the students were looking to the teachers as well as their own parents since all—teachers, students, parents, and guardians—were working, teaching, studying, or learning from home.

Indeed, it was the first time in my life that I had to leave in-person classrooms and provide students with adequate physics online learning resources and curricula in a very complicated era of the COVID-19 pandemic. It was a huge challenge for me since not only I but most teachers had not ever heavily relied on online teaching and learning before this pandemic (Schleicher, 2020; Çoban, 2021). The figure below demonstrates that lower secondary teachers across OECD countries were interested in in-person courses or seminars rather than participating in distance learning and virtual professional developments in 2018. China and Korea have the most teachers interested in virtual settings (teaching and learning online) in 2018.

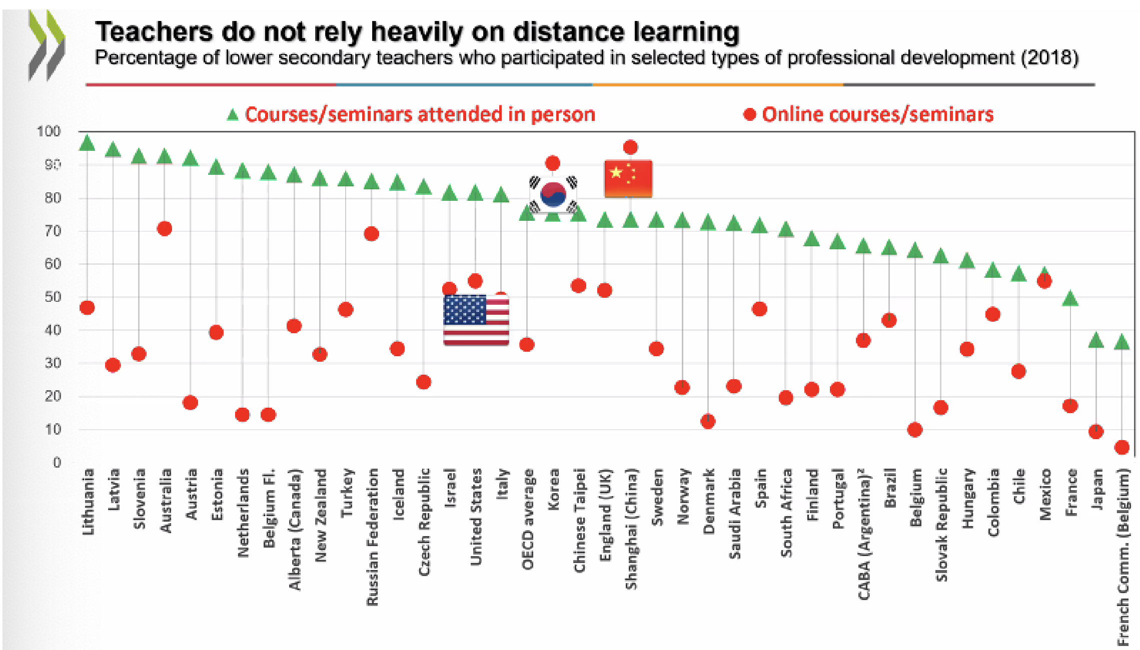


Figure 5.1 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

To me, online learning seemed impossible at the beginning of the pandemic in 2020; however, after less than a month of attending and observing my own doctoral classes (online) at SFU, virtual events, virtual conferences, virtual workshops, and virtual webinars nationally and internationally, everything became absolutely possible and tangible; there were even intriguing moments of transformation with the help from technology, and unprecedented opportunities for innovation and creativity in education

(Schleicher, 2020; OECD, 2020c, 2021b; Schleicher et al., 2021). Nevertheless, teaching physics online was difficult without being able to conduct in-person experiments and demonstrations.

However, I had the wrong idea. It was the impact of my traditional mindset about teaching and learning physics that I carried at the beginning of the pandemic. Technology and digital devices could strongly support and scale innovative teaching during this time, as asserted by Schleicher in his webinar in 2020. A great many innovative learning environments and approaches are emerging, and the need for professional development is high in education (Schleicher, 2020). We become innovators and creators due to necessity. Our place in education, the classroom, and learning environments is being reshaped by the crisis of COVID-19. In this regard, the figure below shows the impacts of Covid-19 on education and remote learning across the OECD countries in 2020.

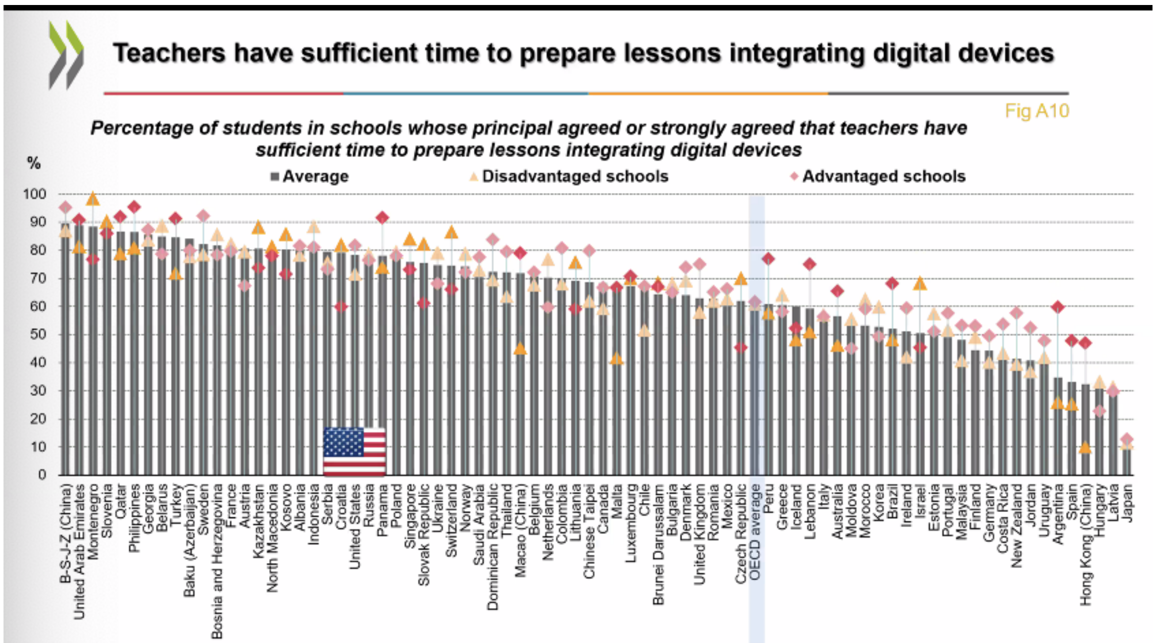


Figure 5.2 **Schleicher, A. (2020, Nov 17). OECD. Impacts of COVID-19 on Education and Remote Learning. What Comes Next?**

The graph demonstrates how countries and their educational systems were prepared for “integrating digital devices” during the COVID-19 pandemic in 2020. Consequently, with the subsequent imposed pause and disruption in the world, the opportunity presented itself for me to start again and prepare my lessons by “integrating digital devices” and technology and modernizing my curriculum and pedagogy. Disruption became an opportunity for innovation as school closures as well as technology provided teachers with adequate time to prepare for the necessity for change (Schleicher, 2020, OECD, 2021b). In sum, new goals can be achieved with old structures.

Indeed, it was a critical time for me to rethink and redesign the SCP's curriculum as well as my pedagogy. With the COVID-19 crisis, daily public health authorities' updates on Covid cases, the number of deaths, and health concerns caused stress and anxiety to escalate in society. I had to aim to overcome these pressures and challenges. *Contemplative* practices such as meditation with its positive effects on brain function, as emphasized by Desbordes et al., (2012), Condon et al., (2013), Smith (2018), Bai (2013), and level of *flow*, as considered by Csikszentmihalyi (1990, 1996) could be the best choices to survive. As such, I attempted to meditate differently with different things in a different time, in general a different meditation—meditation during the toughest and most complicated time of my life. It was a great solution for my well-being. What kind of meditation am I talking about? What kind of meditation is possible under the described circumstances and how? In short, difficulties—darkness—became a great opportunity for me to meditate by writing a science curriculum—to relax, to focus, to see, to gain energy, to imagine something better, and finally to be able to create something.

5.1.2. Meditate Differently with Different Things in a Different Time: Curriculum Writing

What is the definition of meditation? When do we feel that need to meditate? How can we meditate? What happens during meditation? Why do we meditate at all? And finally, what would be an outcome of a good meditation? In general, the definition of "meditate" according to the online Cambridge Dictionary means "to think seriously about something, esp. over a period of time," "if you meditate, you give your attention to one thing, and do not think about anything else, usually … as way of calming or relaxing your mind" (The Cambridge Dictionary, n.d.). It means "to think deeply or focus one's mind for a period of time, in silence or with the aid of chanting, for religious or spiritual purposes or as a method of relaxation" (The Cambridge Dictionary, n.d.). From these definitions, it is comprehended that an individual's mind starts focussing and profoundly thinking of one specific thing and matter while thoroughly disconnecting the thought and mind from other things, like a strong and deep concentration. There is a feeling of joy in such concentration and involvement, much like the experience of a passionate and creative artist in the process of creation of the best work (Csikszentmihalyi, 1990, 1996, 1997). Csikszentmihalyi (1990) claims this experience of concentration with joy as flow theory. The person with that specific concentration, contemplation, and flow, first, starts encompassing and considering a particular matter or thought; second, starts attempting and deciding on that thought and idea; and eventually, starts designing those thoughts or ideas in a way that could have a different outcome. I believe that people meditate differently with different things at different times. These various ways of meditating not only grant them joy and passion but also enable them to gain energy to envision, explore, and create in the next steps.

To make it clear and tangible, I refer to myself and my lived experience of meditating differently with writing a physics curriculum. It was the late spring of 2020 that I initiated designing and writing physics curricula for an enrichment science program for grades 6 to 9 students. Studying physics has always brought me a particular concentration, joy, and focus that I could barely find with other work and practice, and I was enthusiastic and passionate about my efforts. Anytime that I was involved with writing and preparing the curriculum, I had no idea of time and place. It was like a contemplative practice for me. It was like a meditation when you disconnect yourself from others and your surroundings and just focus on one thing. Meditating with my curriculum writing during that difficult time brought me serenity, tranquillity, and silence. Though my mind was busy writing content, I was gaining energy in this process. I felt no tiredness, as my mind and body were recharged as I produced the work and enjoyed "the process of creation for its own sake" as argued by Csikszentmihalyi in flow experience (1996, p. 6). It seems that I have found a new way to do contemplative practices and meditate with my work—physics curriculum writing.

I believe it takes some practice to meditate with different things, but it is achievable and worth the effort. In this way, we can enjoy our time and work and can find a new way to spend our energy which is not being drained and leaked as argued by Bai (2013). This is the reason that, for example, philosophers and scientists may have meditated for hours and hours and gained energy to be able to relentlessly write or unceasingly investigate for days and nights. Researchers, poets, rock climbers, cyclists, surgeons, dancers, and even composers with their flow experiences in their own complete immersion (Csikszentmihalyi, 1997) meditate differently with different things.

We—educators, teachers, and leaders— may help students construct cultures in environments and societies whose people have learned to meditate with their work (whatever their work is). In other words, we need to help students find their real passion and interests at the right time in order for them to succeed in a future full of uncertainties.

5.1.3. From Waves to Quantum Physics—Theory to Practice

> *I have my own things to say and to talk about and there's no implication that anybody needs to talk about the same thing or anything like it.*
> *(Feynman, 1982, p. 467)*

Now, I am ready to initiate working on Level 2 SCP's curriculum, adapted to the Fourth Industrial Revolution and updated to cater to the future-ready young students of the 21st century. This curriculum has been carefully rethought and redesigned for the students who, by 2024, will be identified and described according to their scientific knowledge, scientific competencies, and scientific identity at the age of 15, as emphasized in a report from OECD (2020b). Paul Davies states, "The nineteenth century was known as the machine age, the twentieth century will go down in history as the information age. I believe the twenty-first century will be the quantum age" (Laforest, 2015, p. 5). As such, the main educational objectives according to Ralph Tyler (1949) are intertwined with our contemporary life significance in response. Thus, one of the main aims should be to ease students' learning path towards modern physics with its new ways of looking at the world (quantum mechanics) at early ages (He et al., 2021; Venegas-Gomez, 2020; Akdemir et al., 2021; Franklin et al., 2020a, 2020b; Krijtenburg-Lewerissa, 2017). The results of some studies disclose that this is doable for young pupils (Duit et al., 1997; Stavrou et al., 2008). The aim is to spend less time on classical (Newtonian) physics and let the youths explore modern and *contemporary* science and knowledge; let them know that there are many different ways of thinking and solving problems rather than using the classical foundations and principles.

I strongly agree with Dewey's perspective that students benefit the most from the content learning when they can relate it to either their background knowledge or preceding experiences (Dewey, 1902) since they can effectively develop and deepen their understanding and knowledge. This is why I designed most of Level 2 of the SCP with a particular focus on *waves* and related principles and concepts like reflection, refraction, diffraction, and interference. The aim was to build a required background knowledge for 8th and 9th graders to effectively use for learning quantum concepts later in Level 3, in addition to magnetism and astronomy in Level 2. In short, I attempted to help students build their knowledge and experience in the most contemporary-related concepts and issues like quantum mechanics in the mathematical sciences—physics.

5.1.4. Why Quantum Physics …?

> *Quantum supremacy is a worthy goal, notable for entrepreneurs and investors not so much because of its intrinsic importance but rather as a sign of progress toward more valuable applications further down the road.*
> *(Preskill, 2018, p. 7)*

In this section, I will look at the importance of quantum physics from various angles and perspectives. From any ethical directions, we will be satisfied that we are benefitting from learning quantum physics, or at least from knowing its significant principles, as it gives us an opportunity to familiarize ourselves with a completely different way of thinking and looking at and solving problems (Preskill, 2018; Laforest, 2015; Barad, 2007). Reality is quantum (Feynman, 1982, 1985; Mashhadi & Woolnough, 1996). In quantum, the way we see, think, perceive, justify, and conclude is utterly different from classical physics (Barad, 2007; Laforest, 2015; Mashhadi & Woolnough, 1996; Feynman, 1982). This is the reason it is called modern physics, which can be related to everything connected to knowledge, even philosophy and social sciences (Barad, 2007).

Though quantum is a topic and concept established under the subject of physics, it is being developed and utilized in other subjects and sciences like chemistry, biology, and engineering (Marx, 2021; Piattini et al., 2020; Raghunandan et al., 2019). Quantum is an intersection connecting the physical, biological, and digital technologies of the 21st century and the Fourth Industrial Revolution. Indeed, quantum mechanics brings us a sense of ascendency in the 21st century. Physicist John Preskill, the Richard P. Feynman Professor of Theoretical Physics at the California Institute of Technology, and Director of the Institute for Quantum Information and Matter at Caltech, proposes the term “quantum supremacy” and accentuates that “this is a privileged time in the history of our planet, when information technologies based on principles of quantum physics are ascendant” (Preskill, 2019, n.d.). Why do we really choose, speak, and focus on quantum mechanics?

Classical physics, with a set of rules and theories, describes nature, the world, the interactions between large objects, and what we experience in our everyday lives like the motions of an accelerated car, a flown airplane, a floated ship, a moon around a planet or a planet around a star in the universe, or even the work of magnetic fields and electrical circuits in our daily communications. However, classical physics is not the only fundamental description of nature and our everyday life experiences in the world (Feynman, 1982, 1985). There are many more different theories and ways to think, to see, and to experience reality than what was experienced and discovered by the physicists like Galileo, Newton, Einstein, Maxwell, and other scientists who worked in the field of classical physics (Laforest, 2015).

The interesting part is that classical physics does great things for nature and ***large*** objects, but it totally fails when it tries to describe the behaviour and nature of a phenomenon that we experience every day: *light* (Feynman, 1985; De Broglie, 1929; Walker, 2002; Hawkes et al., 2014). It fails to describe the behaviour of extremely ***small*** objects in atomic sizes (Feynman, 1982, 1985; De Broglie, 1929; Walker, 2002; Hawkes et al., 2014). It fails to describe the behaviour of the building blocks of nature—atoms—for instance, the motion of electrons around the nucleus of an atom (Feynman, 1985; Laforest, 2015; De Broglie, 1929; Hawkes et al., 2014; Walker, 2002). Then, how does physics speak at an atomic level and describe the behaviour of atoms? How does physics describe the reality and nature of light phenomena? Our answers come from a thoroughly different approach than classical physics. Our answers are found in different ways of thinking, seeing, and experiencing the realities. Our answers are not in the rules discovered in the 18^{th} and 19^{th} centuries but in Modern Physics with its strongest and most accurate and validated theory—Quantum Mechanics—introduced in the 20^{th} century and applied in the 21^{st} century (Barad, 1995, 2007; Feynman, 1982, 1985; Laforest, 2015; Hawkes et al., 2014; Walker, 2002). Quantum mechanics beautifully and quintessentially describes the behaviour of light and its particles—photons—which is called wave-particle duality (Barad, 2007; Feynman, 1985; De Broglie, 1929; Eichmann et al., 1993; Walker, 2002; Hawkes et al., 2014). It is the behaviour that all quantized things like electrons, protons, and neutrons show in an atom (Barad, 2007; De Broglie, 1929; Walker, 2002; Hawkes et al., 2014). Their behaviours cannot be described and justified in classical physics (Barad, 2007; Feynman, 1985; De Broglie, 1929; Walker, 2002; Hawkes et al., 2014). We need to step into and learn from modern physics with its own ways of looking at nature and its phenomena (Barad, 2007; Feynman, 1985; De Broglie, 1929; Walker, 2002; Hawkes et al., 2014).

Our current life has strongly relied on and mingled with digital devices and technology, and the crisis of COVID-19 has enhanced this relationship and reliance more than ever. For instance, optical telecommunications, light-based quantum technologies, light detectors, and sensors in our digital devices such as smartphones and smartwatches are well-known technologies in our everyday life experiences (Hawkes et al., 2014; Walmsley, 2015). Efficiency and sensitivity of sensors can be significantly enhanced with quantum mechanics which, for example, can be useful in *early cancer detection* (Taneja, & Singh, 2020; Fu et al., 2006; Raghunandan et al., 2019) or *geological explorations* (Faley, 2019; Lozada Aguilar et al., 2018). Quantum computing, by focussing on the quantum behaviour of atoms and quantum objects, can develop *drug designs* (Peters et al., 2006; Raghunandan et al., 2019) and *machine learning* (Schuld et al., 2015; Sarma et al., 2019; Gohel & Sharma, 2012). *Quantum-safe cryptography* (Fernandez et al., 2019; Wang et al., 2021), *quantum teleportation (for transferring information)* (Bennett et al., 1993), *satellite-based global quantum networks* and *quantum internet* can develop high security in communication and global networks (Kimble, 2008; Wehner et al., 2018; Yin et al., 2017; Harney & Pirandola, 2021; Valivarthi et al., 2020; Brito et al., 2021). Consequently, all these advanced quantum devices such as quantum computers (Venegas-Gomez, 2020) which "would be able to efficiently simulate any process that occurs in Nature" (Preskill, 2018, p. 2) and quantum networks (Nielsen & Chuang, 2010; Briegel, Dür, Cirac & Zoller, 1998), with quantum computation and quantum information (Dowling & Milburn, 2003), are produced, developed, and engineered with quantum materials, for instance, to increase the capacity of storage and maximize the efficiency of electricity transportation with zero loss energy (Yu et al., 2019; Tokura et al., 2017; Liu et al., 2020; Jean et al., 2017).

Indeed, in science education, is it not worth learning the fundamentals, concepts, and sciences behind these technologies and their influential everyday experiences? In the process of connecting contemporary life and the curriculum of content learning, is it not necessary to take care of the contemporary aspects, factors, and matters (Tyler, 1949) that would prepare students to solve the problems of today and in the future, since these problems and concerns unprecedentedly will change not only due to the Fourth Industrial Revolution (Schwab, 2016, 2017, 2021; Schwab & Davis, 2018; WEF, 2020a, 2020b) but also because of the nature of science (NOS). For instance, physicists and researchers are still striving to explore more in quantum physics and overcome some major challenges, such as using light to build a quantum computer (Walmsley, 2015; Preskill, 2018). This is where we need to bring passionate young students in, as stated by Feynman (1982): “Physical knowledge is of course always incomplete, and you can always say we’ll try to design something which beats experiment at the present time […]” (p. 468). This is where our *young scientist*s can think of the use and ethically develop quantum physics for the future.

Is it not worth preparing our young students for the several industries that need specialized professionals in quantum computing (He et al., 2021)? Approximately 600,000 new job opportunities will be available in quantum-related fields in 2040 (He et al., 2021; Venegas-Gomez, 2020). This aim asks for revolutionary initiatives in a physics science curriculum (He et al., 2021; Venegas-Gomez, 2020; Akdemir et al., 2021; Franklin et al., 2020a, 2020b; Krijtenburg-Lewerissa, 2017; Duit et al., 2014; Olsen, 2002; Science, Technology and Innovation Council, 2015; CCA, 2015; DeCoito, 2016; 2015; Xu et al., 2015; NSF, 2020; Amgen Canada and Let’s Talk Science, 2019). Therefore, to respond to future industry needs and career opportunities, we need to prepare an extremely skilled and educated quantum workforce today (He et al., 2021; Amin et al., 2019; Venegas-Gomez, 2020). For this aim, we “need to introduce quantum concepts early on in K-12 schools since the learning of quantum is a lengthy process” (Amin et al., 2019; Venegas-Gomez, 2020; He et al., 2021, p. 418). This is exactly what I emphasize in this study. To sum up, the Science Circles Program demonstrates how, in the lower grades, a curriculum that focusses on one aspect of science knowledge and a big idea can develop an advanced understanding of complicated concepts like quantum.

5.1.5. Consciousness, Philosophy, and Modern Physics

What resonates with me most is the emphasis on ethically viewing and experiencing knowledge via modern physics, quantum mechanics. In *Philosophy as a Way of Life,* Pierre Hadot (1995) connects wisdom to justice and illustrates the person “who is in training for wisdom” and eschewed injustice (p. 265). Unequivocally, there should not be any relation and connection between wisdom and injustice, which must be erased with wisdom. People who ameliorate their thoughts and soul with knowledge contemplate the universe and whatever is beyond the Earth. They let their soul, thoughts and mind freely and attentively grow and understand beyond the appearance and manifestation of everything. Wisdom keeps them away from seeing anything small, insignificant and limited to its *space*, *place*, and *time*. Wisdom brings them a sense of belonging, committing, respecting, responding, and caring. It means they look at and perceive facts and things as a whole and all related to one another; it seems they are relatives (Meyer, 2013). Therefore, as they don't perceive "small," their city is the whole world (Hadot, 1995).

Wisdom alters the interpretation of wealth, civic rights, and humanity for every person who arguably contemplates beyond the temporal (physical) and worldly matters and facts. The wisdom lovers, "philosophers," do not see "small" since they count themselves as the smallest in the city of the universe; therefore, every other thing is considered first and not neglected. That is "a mode of existing-in-the-world" and "a way of life" which was called "philosophy" in the Hellenistic and Roman eras (Hadot, 1995, p. 266). I strongly believe that "philosophy [is] a method of spiritual progress which demand[s] a radical conversion and transformation of the individual's way of being" (p. 266). This alteration happens when we are able to interpret the world differently. Humanity is something that has been gifted to us though it needs great care, and we must endeavour to become better human beings.

Manulani Aluli Meyer (2013) argues that there are three main ways that wisdom is experienced, and knowledge is viewed in the world (p. 94). She believes that people experience knowledge via the real and tangible physical world, like science, via a virtual and invisible but existing world like thoughts, beliefs, or an image that has been created by light (energy), natural phenomena. Finally, people acquire knowledge via a spiritual dimension that is a progressed level and stage of the experience. Meyer beautifully relates this spiritual aspect of life to a concept and theory that is the interaction of energy and matter in the science of physics. In other words, Meyer (2013) attempts to relate the physical and virtual aspects together by stepping out and going beyond the norms. When she explores the relationship between matter and energy and talks about quantum (the knowledge that can describe the behaviour of the *smallest* objects), she refers to the *smallest* amount of something that we can have. Moreover, this smallest amount is a fundamental framework for understanding and describing nature and creating a whole. Thus, being and seeing the *smallest* in the world and contemplating beyond that subsequently brings consciousness and intentionality itself. This is what we need today.

5.1.6. Nature of Science Calls on Young Students

The nature of science (NOS), "a more encompassing phrase to describe the scientific enterprise for science education" (McComas, 2002, p. 4), paves the way for young, interested students to make scientific discoveries in the future. Though NOS is a "body of knowledge, method and way of knowing" (Lederman, 2007, p. 833), the majority of high school students and teachers, even general citizenries, do not have an adequate understanding of NOS (Lederman, 2007, 2013). People with knowledge and comprehension of the NOS can understand the "values, limitations, and impacts of science and technology on society" (Sangsa-ard et al., 2014, p. 382).

Clough and Olson (2012) claim that students' understanding of science depends on applicable NOS instruction (Sangsa-ard et al., 2014). They assert that understanding NOS not only helps students to comprehend and use the assumptions that cause scientific knowledge but also motivates them to learn and teachers to teach the science content (Sangsa-ard et al., 2014). Moreover, researchers argue that "students' insufficient understanding of NOS" is related utterly to "curricular approaches" despite the fact that teaching NOS is underlined in science education (Kahana & Tal, 2014, p. 1). Accordingly, students need to be familiar with and educated on not only the concepts and knowledge of science and technology but also with the views and aspects of NOS.

The nature of science is now more highlighted since it is the actual aim of science education (Lederman, 2007, 2013). In *Nature of Science: Past, Present, and Future*, Lederman (2007, 2013) discusses the importance of *understanding NOS* by pointing to Driver, Leach, Millar, and Scott's (1996) arguments that understanding NOS "is necessary to make sense of science and manage the technological objects and processes in everyday life;" "is necessary for informed decision-making on socio-scientific issues;" "is necessary to appreciate the value of science as part of contemporary culture;" and eventually "facilitates the learning of science" (Lederman, 2007, p. 831-832).

As mentioned already, the nature of science naturally points to the "epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman, 2007, p. 833). Lederman (2007, 2013) argues that students should be able to distinguish the differences between *observation* and *inference*. Observations are descriptions of natural events while inferences are the explanations of those observations (Lederman, 2007, 2013). The scientists' observations and inferences all are scientific while "scientific knowledge is subjective and/or theory-laden" (p. 834). Lederman (2007, 2013) indicates other important aspects of science related to "human imagination and creativity":

> Even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a totally lifeless, rational, and orderly activity. Science involves the invention of explanations, and this requires a great deal of creativity by scientists. This aspect of science, coupled with its inferential nature, entails that scientific concepts, such as atoms, black holes, and species, are functional theoretical models rather than faithful copies of reality. (Lederman, 2007, p. 834)

The most significant perspective in science and NOS is that the scientists with their *imagination and creativity* infer the observations. Lederman (2007) states that "scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work" (Lederman, 2007, p. 834). As such, the scientists' background affects their investigations, observations, and interpretations of the results (Lederman, 2007). Science is hardly based on neutral observations despite the common belief (Chalmers, 2013; Lederman, 2007, 2013); the "production of scientific knowledge" is "subjective" because of scientists' "individuality or mind-set" (Lederman, 2007, p. 834).

In addition, scientific knowledge, which encompasses *facts, theories and laws*, is tentative and changeable (Lederman, 2007, 2013), and strongly but not completely relies on "observation, experimental evidence, rational arguments, and skepticism" (McComas, 2002, p. 6–7) . There are diverse ways to do science which is an endeavour to elucidate natural phenomena (McComas, 2002). The point here is that scientific knowledge is "inferential," "creative," and "socially and culturally embedded" (Lederman, 2007, p. 834). In other words, science is rooted in social and cultural traditions and has demonstrated both evolutionary and revolutionary character during history (McComas, 2002). As such, “scientific ideas are affected by their social and historical milieu” (p. 7). For the reasons mentioned above, Lederman (2007, 2013) claims that the knowledge of science is subject to change in the future regardless of how much supportive evidence there is.

The next significant step is differentiating between scientific laws and theories. Theories do not become laws regardless of any evidence and support; besides, laws are not higher in status than theories (Lederman, 2007, 2013). “Laws are statements or descriptions of the relationships among observable phenomena” whereas “theories, by contrast, are inferred explanations for observable phenomena” (Lederman, 2007, p. 833–834). Theories are as authoritative as laws; moreover, they are not interchangeable (Lederman, 2007, 2013).

Furthermore, it is essential to recognize the differences between NOS and scientific processes. According to the AAAS (1990, 1993) and NRC (1996), “scientific processes are activities related to collecting and analyzing data, and drawing conclusions” (Lederman, 2007, p. 835) such as observations and inferences. On the other hand, “NOS refers to the epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge” (p. 835). Understanding NOS is not only necessary to comprehend science and facilitate technological substances and life developments, but it also enables and helps science education.

Lederman (2007, 2013) posits that according to the American Association for the Advancement of Science [AAAS] (1990, 1993), Klopfer, (1969), National Research Council [NRC] (1996), National Science Teachers Association [NSTA] (1982), NOS is an “objective in science education” (p. 832). After 50 years of research in this field, Lederman (2007, 2013) expresses that K-12 students and teachers do not have “adequate” understanding of NOS. He asks: “Is it really important for students and the general citizenry to understand NOS?” (p. 831). He points to “high school graduates and the general citizenry [who] do not possess (and never have possessed) adequate views of NOS” (p. 831). Thus, the extent to which people understand NOS is concerning (McComas, 2002).

Consequently, since students’ understanding of NOS has been “naïve” and “inadequate” (Sangsa-ard et al., 2014), they need to become familiar with it, that is the body of knowledge, scientific methods, and techniques that introduce science and technology to K-12 students through science education. They need to understand how NOS calls on their imagination, creativity, and background knowledge with its tentativeness. Kahana and Tal claim that students' understanding of NOS has recently improved slightly by teachers doing inquiry-based projects (Minner et al., 2010) and "teaching cases in history of science" (Kahana & Tal, 2014, p. 1).

5.1.7. Quantum Physics for Youths

> *Science education has the capacity to help support and equip young people with the knowledge, skills and identities (agency, attitudes, experiences, and personal and social resources, such as resilience) that will enable them, their communities and societies to tackle many challenges in the next decades. The extent to which young people are able to critically engage with and use scientific knowledge and competencies in their lives beyond the classroom will be important not only for them personally, but also for the health, fairness and prosperity of societies globally.*
>
> *(Organization for Economic Co-operation and Development, 2020b)*

The Science Circles Program (SCP) attempts to help young students to effectively know, explore, learn, and reflect on the basic principles and concepts of mathematical sciences, and physics, as well as contemporary topics and problems in science in which they can understand the nature of science too. Since 2020, SCP offers an updated curriculum with adapted educational objectives for not only our contemporary life, with its significance underscored by Tyler (1949), but also for the Fourth Industrial Revolution, introduced by Schwab (2016, 2017, 2018, 2021). Granted in the program are new, eclectic curricular directions (changes) (Schwab, 1969), updates with contemporary pedagogical tools, and diversion of theory to practice (Schwab, 1969) by subject matter and curriculum/education specialists (Dewey, 1902; Tanner, 1991) whose teaching approaches are progressive and student-centered in supporting students' active learning, according to Dewey's theory of learning (Dewey, 1916).

I, as the program's director, curriculum and instructional designer, and instructor, endeavour to make the most complicated concepts and topics of mathematical science simple, understandable, and tangible for youths in SCP. For instance, quantum physics, one of the most challenging topics in physics, has been simplified and designed with help from various updated scientific resources and pedagogical tools for adolescents who are in a formal educational system in grades 8, 9, and 10. According to the students' assignment submissions and the results of their assessments throughout the program, SCP in Level 2 could successfully demonstrate that young students (grades 8 and 9) are able to develop a clear understanding of the basic principles of waves with the designed *wave-quantum-curriculum* towards learning the concepts of quantum physics. Their learning is subsequently completed and affirmed in Level 3, accordingly.

5.1.8. What Is Quantum Mechanics Exactly?

Niels Henrik David Bohr (Danish physicist) and Max Karl Ernst Ludwig Planck (German Physicist), the fathers of Quantum Theory, received a Nobel Prize in Physics for their foundational contributions to understanding quantum mechanics, which was later developed by Erwin Rudolf Josef Alexander Schrodinger (Austrian, physicist), Werner Karl Heseinberg (German physicist), Paul Adrien Maurice Dirac (English physicist) and many others in the first half of the 20th century (Hawkes et al., 2014; Walker, 2002). While quantum mechanics has been carefully defined and described by many physicists, its nature is still in progress. Due to my teaching and learning objectives aimed towards simplifying quantum physics, I refer to Rebecca C. Thompson, a physicist and author of the popular Spectra series of comic books about physics, and Head of the Office of Education and Public Outreach at Fermilab. Her simplified interpretation of quantum mechanics is as follows:

> Quantum Mechanics is a way of looking at the very small things that make up atoms, like neutrons and electrons, and other small bits like photons [light particles]. Things that are small don't behave the way you would think they should. They pretty much behave exactly the opposite of how you think they should, but physicists can describe how they work using Quantum Mechanics. (Thompson, 2014, p. 6)

From Thompson's description, it is perceived that in quantum mechanics we are exploring views and experiencing ways which are far away from what we are used to in classical physics. Things behave differently and opposite to what we think they should do normally. This is a new and beautiful world of thoughts and logic based on the principles of quantum physics. Now let us see what the word "quantum" itself means and how Thompson (2014) clearly and simply explains it. "Quantum" means

> something that comes in specific amounts. Electrons have a charge of 1.6×10^{-19} coulombs. You can only get charge in that amount, not 2.3×10^{-19} coulombs or 1.0×10^{-19} coulombs. Charge has to come in multiples of 1.6×10^{-19}. It is "quantized." "Quantum Mechanics" is a way of looking at the "mechanics," or interactions, of these small, quantized

> things. Charge isn't the only thing quantized, energy is too. … The energy of these electrons is also "quantized." (Thompson, 2014, p. 6, 7)

Thompson (2014) in PhysicsQuest: Spectra's Quantum Leap not only clearly explains quantum mechanics' conceptual content but also creates hands-on activities led and followed by a comic book, which is the adventures of Spectra. The beauty of her work is in her tangible and understandable interpretations of quantum mechanics, besides the affordable, cost-effective, and easily accessed materials for the activities. These materials help not only teachers but also students to successfully learn the different ways of thinking and looking at the quantized objects in modern physics.

5.1.9. Quantum Physics and Education: Testing and Measuring

In quantum physics, wave-particle duality, observing, testing, and measuring quantum objects cause them to behave and react differently (Barad, 2007). Quantized objects do not interfere and do not create a pattern while under observation or in the presence of a detector (Barad, 2007). I believe humans behave to some extent similarly to quantum objects and would behave differently while being observed, measured, tested, and competed against. Therefore, they cannot interfere with each other—collaborate effectively—and create a pattern of fringes, freely demonstrating their creativity and innovation. I consider these as reality and not metaphors. Testing creates competitiveness, which may hinder collaborative and constructive conditions in education; this is perhaps why John Dewey does not agree with competitiveness and does not see testing as productive in education (Ayers & Schubert, 2012). Dewey strongly encourages students' collaboration and engagement in not only their own interactive process of learning with their peers but also in the teacher's teaching process too (Dewey, 1902, 1916, 1929, 1986).

In quantum mechanics, when quantum objects are free to interact with each other apart from being detected or measured, in an environment (when they pass through openings), they beautifully interfere and create light and dark areas on a screen—the interference pattern (Barad, 2007). Students are like quantum objects. If we—teachers, parents, administrators, and policy makers—provide them with a proper environment with proper openings and allow them to interact not only with the curriculum but also with each other (their peers) and the teacher to experience learning from theory to practice, they can create beautiful patterns of innovations and solutions on the screen of their education and life. This is what was emphasized by Dewey in “My Pedagogic Creed” in the 19th century: “putting him [her] in complete possession of all his [her] powers” (Dewey, 1897). This is also effective for teachers and all human beings.

Indeed, Dewey strived to empower students’ “complete possession” and their engagement in the 19th and 20th centuries. However, their empowerment was performed with an issue which must be considered and finally resolved in the 21st century. Most of his declarations and important perspectives are completed and asserted with the *masculine* emphasized*,* and words like *he, him, and his,* which illustrate a male-dominated milieu in education as well as society. There is an explicit gender gap in Dewey’s statements and views. This is not something that has emerged only from Dewey’s work; this is a longstanding issue that has been rooted and created in education, particularly in STEM fields.

5.1.10. An Example of Adaption of the Curriculum and Content Sequence with Contemporary Scientific Issues

To fulfill *contemporary educational objectives* and adolescents’ *contemporary scientific knowledge learning,* according to Tyler’s emphasis of contemporary life and educational objectives, Level 2 curriculum of SCP was initiated differently (dissimilar and far away from the field’s norm in the order of the topics and concepts in physics books and high schools’ physics curricula) with *Waves*—Longitudinal and Transverse *Waves*—topic for 8th and 9th graders. These topics have always been included in the late chapters in textbooks and taught in advanced physics and in higher grades like grades 10 to 12 or have never really been focussed on at the high school level (it may differ in various educational systems and their curricula) and have never been initiated in the lower grades like grades 8 and 9 (Duit et al., 2014; Olsen, 2002). Duit et al. (2014) argue that

> physics instruction in school covers a certain canon of content that is quite similar all over the world. Interestingly, most topics of this canon concern rather “old” physics, namely physics of the 19th century. Physics of the 20th century or even current research plays a certain role only in the upper secondary levels. Most teaching approaches for quantum physics and relativity are suited only for rather gifted students of the tertiary level. Serious attempts to make more recent physics thinking about matter, space, and time accessible also for younger or less gifted students have to be intensified. (Duit et al., 2014, p. 451)

Moreover, students have difficulty understanding and learning the related concepts in quantum physics (Barad, 2007; Müller & Wiesner, 2002) such as wave-particle-duality and the double-slit experiment with various quantized particles such as photons, electrons and so on (Olsen, 2002; Duit et al., 2014). From my point of view, students find these experiences complex and daunting not only because they are introduced to quantum too late in their education (Duit et al., 2014) but also because they are initiated with an unfocussed curriculum from classical wave model to quantum model of light or other atomic particles. Therefore, Level 2 curriculum mostly focusses on a conceptual and practical understanding of *Waves* and *Lights* with minimal mathematics, which works well for students in the lower grades or with minimal mathematics skills. These topics create a desired foundation for learning the most contemporary scientific issues and knowledge like *quantum and gravity* (directing towards quantum gravity) while helping to achieve the 21st-century educational goals (Choudhary et al., 2018).

Furthermore, *Waves* and *Lights* were followed by two topics of *Magnetism* and *Astronomy* which were taught and practised differently with various updated hands-on activities and engaging approaches in the curriculum and pedagogy. The lessons were initiated with an introduction to astronomy and magnetism and concluded with the basic concept from *Plasma,* one of the four fundamental states of matter. A masterpiece of curriculum, either created by myself or collected from various resources, includes the *Solar System* with its *Eclipses, Aurorae* and the *Red Shift of the Doppler Effect* towards *Newton's Law of Gravitation* with *Natural and Artificial Satellites* in different *orbits* to examine the *Global Position System* and our locations on *Earth* while virtually travelling to the *Sun* to initiate *Magnetism* and *Magnetic Fields* not only around the *Earth* but also on the *Sun*—from the *Earth's Magnetosphere* to the *Sunspots*, *Solar Flares*, and *Coronal Mass Ejections*—for four of the ten classes of Level 2 SCP.

5.1.11. Examining Teacher and Teaching with Ted Aoki Through Different lenses

While creating resources for the planned curriculum and pedagogy, I was trying to do my best to match my aimed curriculum (curriculum-as-plan) to what I was going to live and experience with my students in reality (curriculum-as-lived-experiences). Ted Aoki (1991, 2005) in *Teaching as Indwelling Between Two Curriculum Worlds*, initiates an argument with the classroom environment of Miss O and the students' interaction and reaction to classroom teaching and learning elements. He attempts to shed light on how Miss O “finds that her pedagogic situation is a living in tensionality—a tensionality that emerges, in part, from indwelling in a zone between two curriculum worlds: the world of curriculum-as-plan and curriculum-as-lived-experiences” (Aoki, 2005, p. 159).

From my point of view, everything has been imbedded in Aoki’s statement of “pupils who are entrusted to her care” (p.159). There is a lot in these seven words. This statement is pregnant with four important points and involves four factors and elements related to pupils, trust, teachers, and care. It demonstrates that curriculum has two sides—the teacher side and student side—as stated by Tanner (1991) about Dewey’s curriculum. As argued by Dewey, “inherently active” pupils who are looking for opportunities with engaging activities for the aim of learning and improving the “self,” “entrust” themselves to the teacher’s knowledge, consciousness, conscience, and care. This is from the student side. However, it is different from the teacher side. A teacher is committed to duties which I consider equivalent to a doctor’s responsibilities, someone to whom people entrust their care at critical moments and conditions in life. I strongly believe that teachers like doctors must have a sworn letter before initiating their work. I also think a teacher’s responsibilities are, in some circumstances, as important as a physician since a teacher’s influence could affect a student’s physical and psychological health in the future.

Indeed, in my opinion, a passionate, knowledgeable specialist teacher will be considerate with their students’ learning and their well-being. A teacher with self-awareness and self-understanding commits to particular ethical ways of teaching, facilitating, guiding, leading, helping, supporting, in fact, caring, by creating a constructive and positive relationship with students. This teacher is overtly aware of the assigned responsibilities: the responsibility of creating possibilities and opportunities and supporting intellectually active learning; letting students thrive and grow; enhancing and improving that innate activeness (in seeking opportunities and activities), as emphasized by Dewey (Tanner, 1991; Dewey, 1902). How can we—curriculum developers, teachers, educators, administrators, principals, and so on—care and support someone when we don’t know enough about their interests, intentions, goals, perspectives, abilities, and so forth? A real teacher cares about all of these factors, not just the content learning.

Aoki (2005) poses a fundamental question here: “Who is a teacher?” (p. 163). From Aoki’s perspective, a teacher is a person who knows students’ uniquenesses; who is accountable for what and how to teach; who institutes legitimacy; who students can trust with their knowledge, consciousness, conscience, and care. Students trust the teacher to educate and guide them towards new possibilities. Aoki mentions not only the student’s trust but also the teacher’s responsibilities, wherever and whenever it is possible, to lesson planning, to marking, to listening, and to being attuned to the student’s care. Moreover, a teacher is committed to “fidelity to an external curriculum-as-plan,” which subsequently will cause “a lack of simultaneous concern for the aliveness of the situation” (p. 162). According to my own practices and experiences, a *teacher* is an enthusiastic, knowledgeable person who brings the two curriculum worlds as close together as possible and make them one (though they are different, and each holds different properties) to create a beautiful pattern of *teaching*.

Students need to be provided with opportunities to exchange their information, knowledge, and experience with others with the aim of having new and more correct observations and imagination in the process of their own learning (Dewey, 1916; Tanner, 1991). From Dewey’s perspective and his conception of a school, competition and grouping students according to their *ages* has been replaced with the importance of cooperation and collaboration in a community. In Dewey's school, *multi-age grouped students* are taught by *specialists* in the discipline with the advantage of keeping a family spirit throughout the school. Older students devote their time to helping some of the younger students with their learning. This approach is being used with young students in SCP. Indeed, Dewey’s school facilitates collaboration and creativity among the students themselves.

By providing students with the opportunity to exchange their knowledge and experience while collaborating with peers (Wentzel & Watkinz, 2016), it is necessary to rethink and reform our pedagogical approaches in our classrooms. I am wondering why the majority of teachers believe that the classroom, with all its equipment—for example, class boards—firstly and mainly belong to them, and then to the students. And why should students be on the board for just a short time (a few minutes, if at all) to solve or write something? What if we reverse that and assume that the class boards should belong to the students first? Why do we not wish them to initiate their learning, practice problem solving (Bonney & Sternberg, 2016; Schwab & Davis, 2018) and critical thinking

(Bonney & Sternberg, 2016; Halpern, 2007), and exchange information and knowledge with one another as a group (Wentzel & Watkinz, 2016) on the class board? Why do we not make the boards their vertical workbook, accessible and observable to everyone, instead of their laptops, visible only to themselves.

Moreover, why do we, physics teachers and educators, think that students should always sit and look at the boards that are being filled and emptied by our writings and knowledge? Why do we not let them actively come to the boards and fill them with their work, thoughts, information, and knowledge while collaborating and interacting with each other? Why do we always wish them to be active without really thinking of a space for making them active? Do we not think that we make them “passive receiver[s] of information” (Loyens & Rikers, 2016) while simultaneously asking them to be an active agent in their own learning? We should carefully facilitate their active participation (Dewey, 1916; Hargreaves, 2005), interactions with their peers (Wentzel & Watkinz, 2016), simultaneously correct their information and work, and provide prompt and elaborative feedback (Hattie & Gan, 2016) on their board work.

The results of studies reveal that providing feedback on students’ work is “among the top ten influences on achievement” (Hattie & Gan, 2016, p. 249) and how frequency and timing of feedback can have effective motivational power in learning (Narciss, 2008). Moreover, Anderman and Dawson (2011) believe that motivation theory can be successful in educational practice and “instructional contexts at all levels (i.e., kindergarten through adult learning) in order to improve student learning” and accomplishments (p. 219). Though students’ beliefs about their own competencies, their way of thinking, and their own individual cognitions are significant factors that play a role in their academic motivation (Anderman & Dawson, 2011), teachers need to provide students with opportunities that can help them acquire and hold such self-beliefs. First students must have trust in their own competencies (believe themselves), and then develop them further.

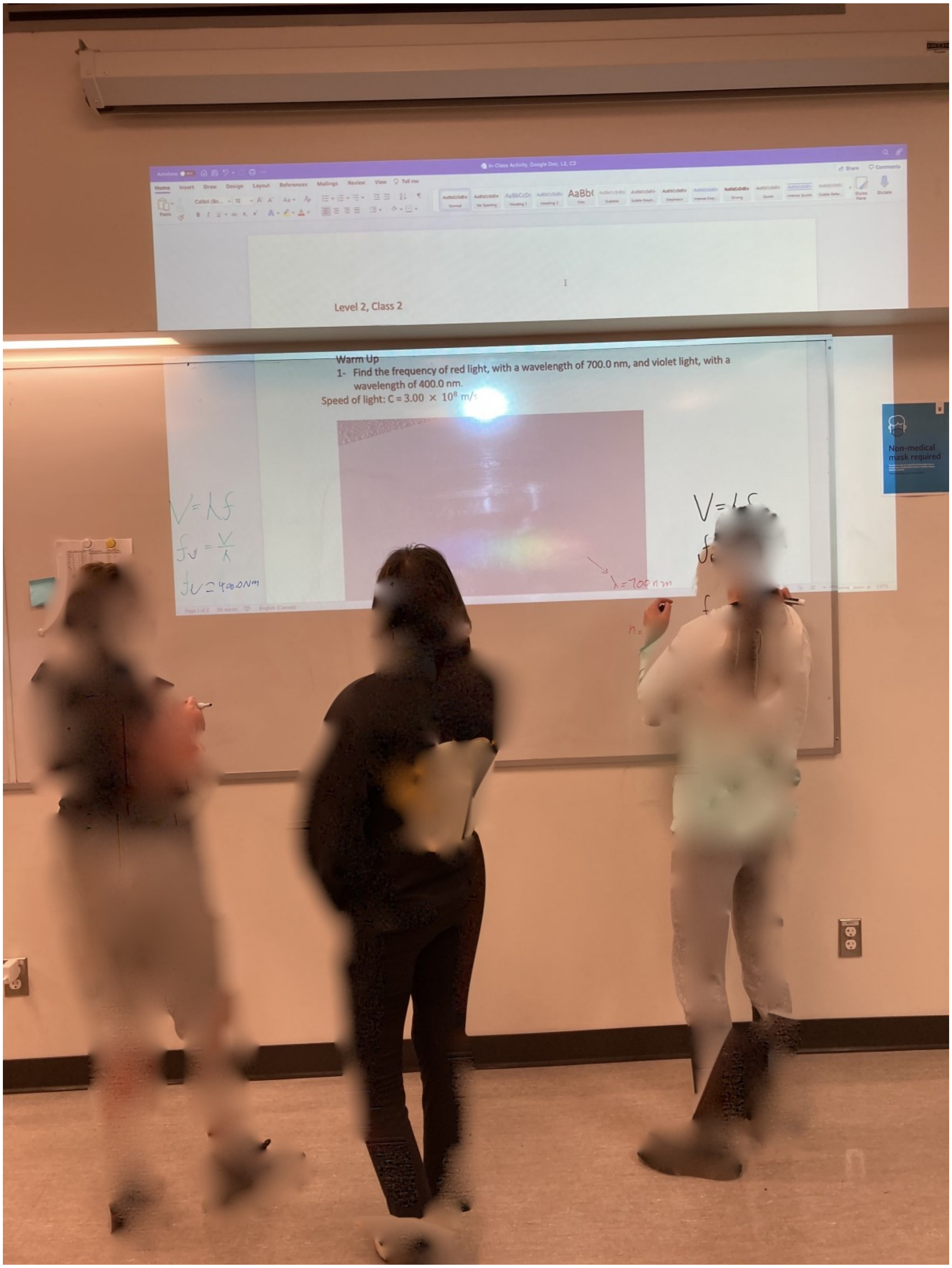


Figure 5.3 Adolescents In-Class Collaborative and Active Problem-Solving Moment on the Classroom Board in an Extracurricular and Enrichment Afterschool Science Program in BC, October 2021.

Photo: Solmaz Khodaeifaal, 2021.

Wentzel & Watkinz (2016) argue the positive motivational impact of students' involvement and interactions with peers on their intellectual development and achievement. Figure 5.3 depicts how young students actively exchange their knowledge and collaboratively practise problem solving (Wentzel & Watkinz, 2016; Bonney & Sternberg, 2016; Krijtenburg-Lewerissa et al., 2017; Schwab & Davis, 2018) and critical thinking (Bonney & Sternberg, 2016; Halpern, 2007), about a real-life experienced phenomenon—spectrum of light—with help from digital devices and technology in my science classroom in BC. These three students are not the only group on the board. As the class has two projectors and five large white boards, each group of students is assigned to a board. The boards without the image of the projected worksheet can be utilized with a printed version (hard copy) attached with magnets to the boards. It is important here to mention that the number of girls that participated in the program exceeded the number of boys as anticipated and argued by scholars (Hsieh et al., 2019; Amgen Canada and Let's Talk Science, 2014; Bennett & Hogarth, 2009; DeCoito, 2016) regarding the higher rate of girls' interest and participation in science learning at early ages.

This is an example of my pedagogical approach in engaging my students in their own process of learning. I provide them with opportunities for collaboration, helping them first become critical thinkers, and then appreciate content learning. Milner-Bolotin (2017a) argues the importance of educational technologies and the positive impact of a technology-enhanced learning environment on students' science learning. Of course, it is not easy work for a teacher. It requires a significant amount of attention and effort to be spent on each student and group work (their attempts) on the boards while I hover over them and quickly navigate between them to facilitate their thinking and understanding. However, this is the way that not only will utterly engage students but also will let them collaboratively and actively learn while practising problem solving and critical thinking, as well as exchanging their reasoning during the class.

In the science classes, youths (in a group of three or four) are either on the boards to demonstrate their knowledge or busy with experimenting and recording a few videos from physics demonstrations in the class. In every session, first we warm up by discussing one or two questions related to the previous class lesson and topics. This is followed by guided inquiries and activities accompanied with, for example, PhET simulations or any other applications besides my indirect or direct instructions, which helps them gradually explore the new relations and concepts throughout their own exploration, collaboration, and exchange. As such, the students' learning cycle will be affirmed and completed with practical experiments or class demonstrations as well as homework completion.

Furthermore, another essential question raised by Aoki (2005) is "What [is] it … to live life, including school life" (p. 163). What does it really mean "to live life"? We are all living our lives with all its ups and downs. Do we not think our aim of asking this question is to examine the level of consciousness, awareness, and perceptions, and our wisdom of life or in life (living moments)? In other words, to what extent do we learn about and enjoy life and living life? Life is learning and vice versa. I perceive Aoki's question regarding to live life as to learn and to enjoy all moments whether they are happy, joyful, satisfying, and pleasant, or depressing, sad, painful, and distressful. All the points are in *learning* and *enjoying* since each of those moments and experiences (whether easy or tough) are not permanent and will end or at least will change. However, how (the way) it ends and changes matters. To learn to enjoy is a skill which can help us live experiences with flow and attunement, scholars believe this is an achievement (Csikszentmihalyi, 1990, 1996; Wang, 2020).

In fact, we wish to improve young students' achievement in learning physics. Therefore, we teachers, parents, educators, policy makers, curriculum designers, and administrators must help them experience flow in their living life (learning). For bringing flow experiences to students, we need to teach them the skill of enjoying and living learning (life). As such, we must prepare and create moments, activities, and opportunities that would provide them with enough space and time for living life (learning) with flow and joy. I believe this is what Aoki attempts to bring to both teachers and students with his view. We, both teachers and students, need to learn to enjoy the moment and bring the experience of flow in living life. Studies have affirmed the challenges and difficulties that students experience, particularly females, in learning physics and in this field of science (Heras, 2017; Duit et al., 2014; OECD, 2016, 2019a, 2019b; AAUW, 2010; Amgen Canada and Let's Talk Science, 2015; Barker, 2018; Francis et al., 2017; Larson, 2014; Archer et al., 2012; Hutchinson & Bentley, 2011; Institute of Mechanical Engineers, 2010; Tripney et al., 2010; Brown et al., 2008; Lewis et al., 2009; Hyde & Lindberg, 2007). Thus, our responsibility should be first to bring to the young students' experiences of flow, feelings of joy, and complete involvement in physics learning activities, experiments, and problem solving. These experiences do not happen without students' autonomy (Shernoff et al., 2003). According to Dewey's theory of learning (1916), students need to become active participants in their own learning processes. Consequently, they must be provided with moments and opportunities through the *teacher's teaching* (both curriculum and pedagogy) that would respond to and fulfill all those constructive and progressive experiences in learning.

Aoki's third fundamental question is "What truly is teaching?" (2005, p.163). For teaching, it is obvious that a teacher needs curricula. Aoki first divides the world of curriculum into two worlds: 1) the world of curriculum-as-plan, and 2) the world of curriculum-as-lived experiences, and then indwells somewhere between these two worlds. Aoki observes Miss O's teaching as "situated in the Zone of Between"—an indwelling in the zone of between curriculum-as-plan and curriculum-as-lived-experiences (p. 163). Moreover, he points out to "the naivete of the linear understanding" which "sees a linear movement from curriculum-as-plan to curriculum-as-lived-experience" (p. 163). I think the reason that Aoki counts the linear movement as a naïve understanding is this: If we accept that the movement between these two zones is linear, then the relationship of the movement between the worlds is always constant. In other words, if we increase one of them (or move towards one of the worlds), the other one should decrease (create distance or move away from the other world) and vice versa. If we situate our teaching in one zone/world, we will be far away from the other zone/world since we assumed their movement is linear. Therefore, I conceive Aoki's view of *teaching* as being beyond the classical and traditional ways of thinking.

By looking through a quantum lens, I see the teaching more like *light,* both here and there. Teaching should be both, curriculum-as-plan, and curriculum-as-lived experiences. It is like a fluctuation—it fluctuates between two zones—while simultaneously can be situated on both. To situate in one zone does not necessarily mean to move far away from the other zone. Our teaching can be 100% situated on both zones at the same time—both here and there. Our teaching can be like photons which behave like particles, and then simultaneously behave like waves. They hold different properties and distinct behaviours; however, they both occur (behave) at the same time. They do not limit themselves to one view or one world. Both are being embraced. This dualism grants an ability to go beyond classical and traditional ways of thinking, looking at, and solving problems. With this dualism, not only photons but also all the other quantized objects are able to create an unbelievable phenomenon of patterns. Let us bring this dualism into our teaching and see if we, teachers, can also create a phenomenon in our teaching moments with both passionate and dispassionate students.

In teaching with duality in science education with curriculum-as-plan-curriculum-as-lived experiences-duality—like wave-particle-duality—the teacher instantaneously utilizes both properties of curriculum-as-plan and curriculum-as-lived experiences to the best benefit of both worlds for creating better teaching and learning experiences in the class. We bring these two different worlds of curriculum together and consider them simultaneously for the aim of defining and creating a world of teaching—world of light—Figures 5.3, 5.4, 5.5. The world of teaching is comprised concurrently of plans and lived experiences as light (both particle and wave). Teaching is indwelling on this duality, both curriculum-as-lived experience and curriculum-as-plan (here and there) though these curricula are interchangeable. Having one does not necessarily mean cancelling the other one, nor does moving toward one mean becoming distant from the other.

"Indwelling dialectically" equals "living in tensionality," which means living school life; "living simultaneously with [both] limitations and with openness" (Aoki, 2005, p. 164). This openness carries "risks" and "possibilities" for a change (Aoki, 2005). Moreover, this place (the zone of Between) is considered as a sanctified place, as asserted by Aoki. If we look at this place with a quantum lens, it is simultaneously on both. It is where students' appreciation of learning happens; it is where students feel engaged, open their minds, and approach new opportunities and possibilities.

Aoki (2005) claims that "the quality of curriculum as lived experiences is the heart and core" (p. 165). This standpoint can be another reason to reject a linear movement between curriculum-as-plan and curriculum-as-lived-experience as the ratio of these two curricula is not constant in reality, and it frequently changes as time passes (over time). The point here is that our issues in teaching and learning in education arise such that curriculum developers and teachers are not able to keep the ratio of curriculum-as-plan over curriculum-as-lived-experiences constant and close to one. In fact, there is usually a huge gap between curriculum-as-plan and curriculum-as-lived experiences. Put simply, curriculum-as-plan has been always greater, heavier, more focussed, and more centred than curriculum-as-lived-experiences. However, for the aim of teaching the skill of learning to enjoy, living in the moment (*live life)*, lived experiences with flow and joy are essential. This analogy acknowledges the significance of curriculum-as-lived-experiences in teaching and learning, as underlined by Aoki (1991, 2005). He states that "total fidelity to an external curriculum-as-plan and a lack of simultaneous concern for the aliveness of the situation do not extinguish the understanding of teaching as 'a leading out to new possibilities,' to the 'not yet'" (Aoki, 2005, p. 163) and argues that curriculum developers, besides "expertness," need "conscious sensitivity" to the "uniqueness of every teaching situation" and lived experiences (p. 165).

Nonetheless, by looking through a classical (traditional) lens, when we talk about lived experiences, we must take into consideration two factors: time and place. We cannot stop time, nor can we turn it back. As time passes, the place of our lived experiences changes. The relationship between time and place demonstrates the pace of the lived experiences, which must be aligned with the curriculum-as-plan, particularly for science. As such, as time passes, we have different lived experiences at various places which could be overtly related to curriculum-as-plan or represent it. In other words, curriculum-as-plan and curriculum-as-lived-experience are truly interwoven and interconnected in science. If we detect a lack of quality in curriculum-as-lived experiences or an absence of this curriculum, it demonstrates the teacher's hesitation and neglect in shedding light on a situation and reminding students of those curricular moments in their lived experiences in the past and present times and various places. Indeed, these curricular moments exist anytime and anywhere. Therefore, teaching is more likely to be indwelling between curriculum-as-plan and curriculum-as-lived experience over time and in different places (Aoki, 1991, 2005).

In teaching physics, learning may first take place outside the classroom and inside students' everyday lived experiences. Physics is the study of fundamental laws of nature and relates to everything in the universe; therefore, the best place to learn physics is nature. For instance, learning about lights, sounds, and different types of waves, such as water waves, are all examples of students' lived experiences—nature-based learning. Moreover, physics learning can be effectively experienced with help from technology at home, the safest place for students to learn. Technology and digital devices can support students' learning particularly during the COVID-19 pandemic (Schleicher et al., 2021; OECD, 2021b). It has been proved that technology can be successful in bringing the physics labs and resources into students' hands anytime and anywhere, like *PhET Simulations*, *Phyphox* (Physical Phone Experiments) *Application* (by touching a figure, they can turn their smartphones into a physics lab), *YouTube* videos (like the recorded and produced instructional and practical physics demonstration videos by expert educators and prior physics teachers), and so on. This is one of the reasons that the Level 2 curriculum of the SCP was purposefully designed with topics and concepts related to the students' everyday lived experiences, which is useful in learning the basics of quantum mechanics.

The visible spectrum of light—i.e., a rainbow—is a great example here. How is a rainbow formed? What causes it? Why does it consist of those colours? Why are the colours ordered from red to violet and are always in the same order and pattern? And what information can be derived from the colours and the way they are ordered? Also, if there are any other lights after the violet and red light, what are the properties of those colourful lights? Do they have the same wavelength and frequency? Do they have the same energy and penetration power? And what is the physics behind all of these questions? In SCP Level 2, 8^{th} and 9^{th} graders initiate their learning with these basic inquiries in physics. They not only effectively understand the basics of electromagnetic waves but can also expand their knowledge to solve a warm-up question for class initiation throughout a collaborative in-class activity in a group of three—Problem Solving Skills. In Figure 5.4, the young students are asked the following:

Find the frequency of red light, with a wavelength of 700.0 nm, and violet light, with a wavelength of 400.0 nm.

Speed of light: C= $3.00 \times 10^{8}\ m/s$

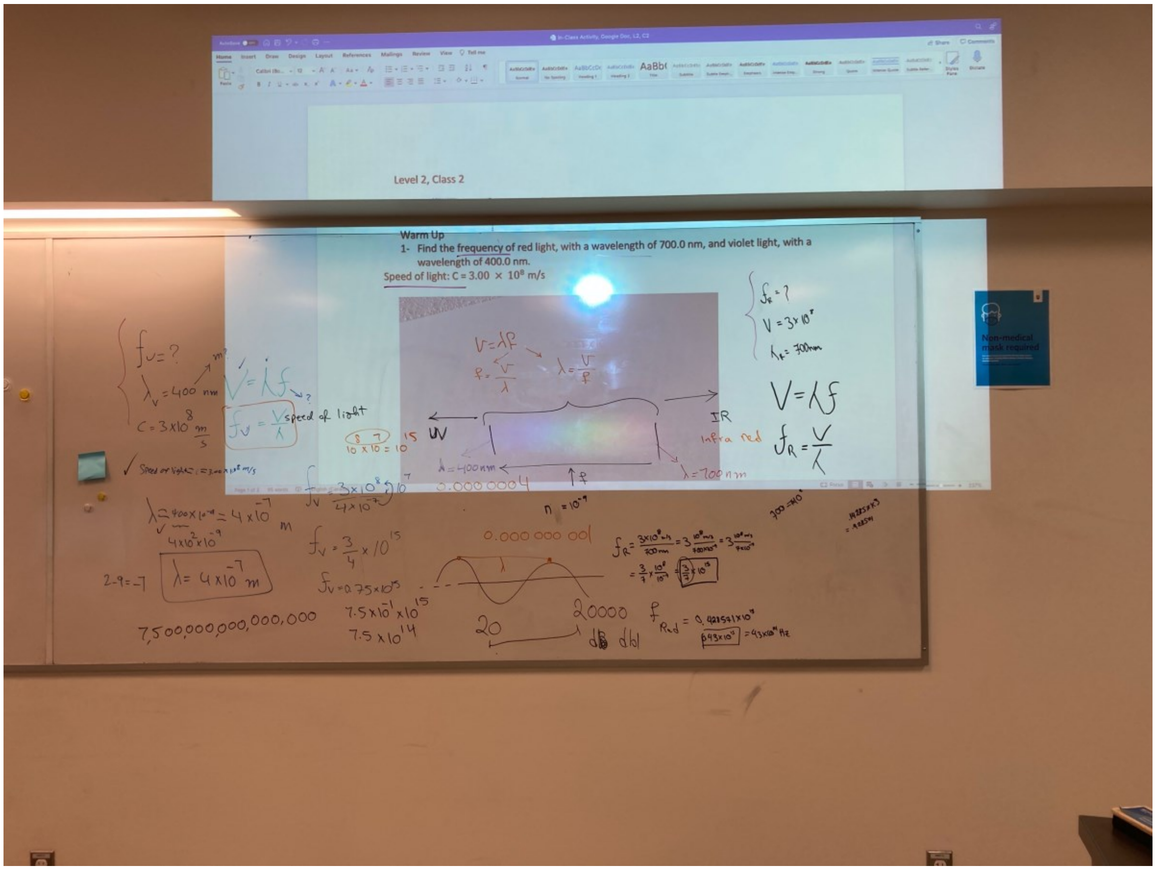


Figure 5.4 Young Students In-Class Collaborative Activity and Problem Solving on the Class Board in Class 2 of the Level 2 SCP, October 2021.
Photo: Solmaz Khodaeifaal, 2021.

Students collaboratively discussed the question from various physical and mathematical perspectives with the related and required concepts such as frequency, wavelength, and speed of light, and how all these three quantities are related together and how change in one of them may or may not affect the other variables. They examined the units and prefixes of the units to understand and imagine the sizes. The concept of exponents besides writing scientific notations were reviewed and practised. Their illustrated work on the board explicitly demonstrated how the physical concepts and mathematical concepts were considered, questioned, and discussed, not only between the students in the group but also with my queries (teacher's intervention and prompt feedback on the student's attempts).

Furthermore, in Figures 5.3 and 5.4, as has been illustrated, the students initiated their work on a worksheet projected on the board with a photo I had taken. It was a rainbow pattern cast on my wall at home due to refracted sunlight from a decorative crystal behind a window. I let the students know where and how this photo was taken as they would learn how it was connected to their everyday life and lived experiences in their home. Moreover, they were assigned to create such a spectrum of visible light and take a photo at home while investigating the phenomenon. Figure 5.5 is the photo that let the students analyze and work on a real image of the light spectrum. If we look at this tangible example from a pedagogical perspective, it could undoubtedly support students' physics learning, let them have a tangible understanding of the concepts, and connect the physics curriculum content to their lived experiences, nature, and real-life situations (context).

Figure 5.5 Two Photos of the Visible Light Spectrum Due to Light Refraction from a Decorative Crystal on the Wall at Home, October 2021.
Photo: Solmaz Khodaeifaal, 2021.

Consequently, according to the results of grade 8 and 9 students' assessments, assignment submissions, class activities, and level of enjoyment, they appeared to successfully learn the properties of all waves, transverse waves, and longitudinal waves like electromagnetic waves (light) and sound waves, with an illustration of water waves (in nature and with virtual simulations) and with its similarity to other kinds of waves with the designed curriculum (wave-quantum-curriculum) and up-to-date pedagogical tools in the program. They learned the basic principles of waves and stepped towards quantum physics by my indwelling on curriculum-as-plan-curriculum-as-lived-experiences-duality.

As we go through the first page of Aoki's article, we see how it illustrates the live(d) pedagogical circumstances in a real in-person and face-to-face classroom. I, as a pragmatist and an advocate of Schwab's practical theory, Dewey's theory of learning with hands-on and collaborative approaches, and Tyler's perspective of contemporary life studies, raise a few questions here:

- What is Miss 0's presence in a Zoom classroom?
- How can she as a teacher establish herself in a virtual situation where there are no desks, chalkboards, floors, books, or resources that we see in an actual classroom?
- How can she establish herself in a classroom in which she cannot even see the student's face but just a name on a screen demonstrating the existence of the student in that class (or sometimes with a relevant/irrelevant photo on top of the name)?
- How does she define engagement, participation, collaboration, and motivation in such a classroom?
- Do we feel the same in an online classroom?
- How does the environment cease to be environment?
- How does the Zoom environment, in its virtual/online place, come to be a pedagogic situation?
- What would be a pedagogic situation in such a classroom?

5.1.12. Need for Relearning, Reskilling, and Upskilling

I would like to remind you of something important here—that I am talking about my experiences in 2020, during the time of a pandemic and global crisis. Schools are closed. There are no in-person classes. I am not going to my regular in-person classes which could help me collect about 20 years' experience of teaching physics and mathematics; where I could create chances to connect my teaching and learning in constructive and progressive moments with a positive educational relationship with young students; where opportunities exist to share my knowledge, passion, care, and love of teaching in a tangible way to young, interested, and uninterested students in physics and mathematics subjects; where I can vigorously and freely move from table to table, from board to board, from corner to corner, from student to student; where I can *see*, feel, and understand students' feelings and sometimes the questions in their eyes and on their faces; where students and I have spaces to experiment in a practical way and learn through hands-on activities; where there are so many things for passionate teachers to talk about forever—about *lived experiences*—and about whatever is happening between them and their students during the teaching and learning interactions—real interactions in its own place.

I mean *constructive or destructive moments and experiences* of teaching and learning in (either in-person or online) classrooms*.* I am talking about *constructive and destructive interference* happening between students and teachers—positive, constructive, collaborative, and progressive experiences of learning moments for students and positive, constructive, and progressive outcomes of teachers' teaching and vice versa—or between students and students—in education, like constrictive and destructive interference of light which creates dark and light areas on a screen. "Thomas Young's two-slit experiment was a singular defining moment in the centuries-long debate concerning the nature of light" (Barad, 2007, p. 97). His experiment demonstrates a wave behavior of light after Newton's "corpuscular" or particle theory of light (Haliday & Resnick, 1986; Barad, 2007). Young illustrates how interference effects occur when two or more waves meet and combine to create a new wave (Haliday & Resnick, 1986; Barad, 2007). In Young's double slit experiment, light waves pass through two very small openings (about nanometers), spread out, diffract from the edges of the slits, and interfere (Haliday & Resnick, 1986; Barad, 2007). In the result of overlapping waves and their interference, a pattern of dark and bright regions is created on the screen (Haliday & Resnick, 1986; Barad, 2007). The bright fringes are the result of constructive interreferences while the dark ones are the result of destructive interreferences (Haliday & Resnick, 1986; Barad, 2007).

In the modern era of the 21st century, we need to shed light on the destructive moments and experiences (destructive interferences caused the dark parts) in education and need to erase them or at least minimize them by decreasing the size of the gaps. It is intriguing how the size of the gaps in Young's double slit experiment affect the width and brightness of the fringes/bands (interference pattern) on the screen (Walker, 2002; Barad, 2007). By decreasing the size of the gaps, the fringes become brighter, whereas increased gaps, after particular sizes, even stop creating the interference pattern on the screen (Walker, 2002; Barad, 2007). For the aim of having positive, collaborative, and progressive patterns in immersive learning and teaching in science education, we must decrease the size of the gaps as much as possible with any available opportunity. As such, I am going to talk about the gaps, difficulties, and challenges for me entering a virtual physics classroom and teaching physics online as well as opportunities for new pedagogical approaches during the COVID-19 pandemic in 2020: needs for relearning, reskilling, and upskilling in 2020.

5.2. Curriculum and Pedagogy Since 2020 with Shifts and Reforms

In 2020, entering a Zoom class for teaching physics reminded me of my first experience of entering a real classroom and the moment of teaching in my life. I had to prepare not only the students' required materials for learning physics but also my own teaching materials and pedagogical tools. However, this time my preparation was to be different, and my work was being impacted by all the changes and challenges of COVID-19 mentioned and emphasized before in this study. Such an understanding and critique of current and future transformations, I argue, allows me to see the gaps and essential needs, plan ahead, and look for ways for improving my teaching and learning. For instance, the first simple change was that there was no physical (in-person) presence, just a virtual/online connection between a teacher and students. As such, there were no hard copies or printed copies of any teaching and learning didactical materials for both teachers and students. Everything had been left behind in the real classrooms. Everything would have to be virtual and online though virtuality itself is now a reality (Liu et al., 2017). Moreover, what I had to do with physics *experiments*, *hands-on activities*, and students' *collaboration*, which were the most important parts of physics learning, were the *practical approaches* as emphasized by Dewey (1897, 1902, 1916, 1929) and Schwab (1969). These scholars' approaches and perspectives "will continue to provide a fundamental ground for explorations into many aspects of science teaching and learning practices and science education […]" (Karaşahinoğlu Fackler, 2020, p. 150) and "are rich in implications" (Black & Atkin, 2014, p. 778).

I am wondering why we (teachers, educators, administrators, parents) think that students must always conduct their hands-on activities and experiments in a physics lab or actual in-person classroom. Not only have technology and digital devices brought physics labs into our hands and with the tap of our fingers but also nature and a student's home can be a real and safe place for learning (Schleicher, 2020). We just need to rethink, redesign and reconstruct a student's physics learning path.

Therefore, I had to design the lessons (curriculum) with demonstrations and activities which either could be attempted virtually, like computer simulations, or could be conducted at the students' home with materials provided by me. What I mean by "materials" here is all the equipment and requirements for hands-on activities, not the learning materials or resources. From here, all lessons embraced various hands-on activities, practical experiments, and demonstrations with technology and digital devices or with cost-effective materials provided in advance to students. As such, I created long lists of materials for each class' activities. They were purchased, collected, organized, packed again and mailed to every online student before the initiation of the program. This approach let the students keep their own pace independently and individually attempt activities at home, before the class, after the class, or during the class (simultaneously with the teacher during the online session). All instructions and guides for each demonstration or activity had to be included in the lessons' resources, and the materials (learning resources) had to be online or virtually accessible for students.

Teachers all around the world were trying to update, connect students with different online platforms, and create effective e-learning content (Reimers & Schleicher, 2020). I started with a well-known software for presentations, PowerPoint, but not only for my presentation in the class. I used it for presenting all required instructional and educational resources to my students with an enquiry-based design for their learning purposes. Resources should aim to both ease the language of science for students and recreate and simplify the scientists' methods and the objectives of scientists' science for students (Izquierdo-Aymerich & Adúriz-Bravo, 2003). As such, I created a PowerPoint for each lesson that included scientific topics and concepts (lessons) with clear and simplified language and stated learning goals; questions; answers; instructional videos; helpful links to other online resources; and detailed guided activities. Dr. Marina Millner-Bolotin, along with myself and other educators at the University of British Columbia, have created many helpful instructional and educational physics demonstration videos for the aim of supporting teaching and learning enhancement in physics education (Millner-Bolotin, 2017b). These have vastly supported the required resources during the pandemic in 2020. Furthermore, the PowerPoints were designed with animations and with proper transitions with adequate time between questions and answers not only to provide students with inquiry-based learning resources (Minner et al., 2010; Loyens & Rikers, 2016; Rodriguez et al., 2020) in physics but also to let them experience inquiry-based learning (Minner et al., 2010; Loyens & Rikers, 2016; Rodriguez et al., 2020) in the flipped classrooms. The PowerPoints became a complete learning resource with a detailed *Agenda* and assigned *Homework Worksheets* related to each lesson for every flipped class. They were shareable and easily accessible and were to be used online on different virtual platforms, not only for students' learning but also for teachers' teaching in virtual classrooms.

However, time was limited, and I had to prepare instructional resources for the students as well as for my own teaching since the classes of 2020, a new school year complicated with a pandemic, were being initiated soon. As such, I returned to my research mode and started again searching for educational and instructional resources which were not only legitimate, accurate, and scientifically accredited for teaching physics but also are updated and adapted with the teaching and learning objectives. Moreover, there were a few more things I had to keep in mind with regards to the resources during my search and preparation for the students like commitment to justice. These materials had *to be free; be open-access educational resources; be under the Creative Commons Attribution license (CC-BY); and be easy to access virtually.* It was the first time in my teaching life that I had to implement effective education responses during a worldwide crisis and time of uncertainty, considering my students' needs on the one side and myself as a teacher on the other. In fact, it is a professional practice and a real solving-problem situation that demonstrates how I have thought in action what has been argued by Donald Schön (1983) as a "reflection-in-action."

Science curriculum was not my only concern; developing an updated pedagogy and utilizing adapted pedagogical approaches and tools in virtually teaching physics to adolescents had to be carefully considered as well. It is significant that our traditional pedagogical methods could fail in our virtual classrooms in 2020. Here was the moment that we could demonstrate the impact of the digital revolution. My pedagogical approaches in in-person classrooms, for example, from what is demonstrated in Figure 5.3, were reformed with technology and computer applications/platforms for online classes in Figure 5.6. This is a part of my lesson plan converted to a pedagogical tool and learning resource for online students' in-class activities, shared with them on Google Drive. I solved the same warm-up question by writing on an iPad that was wirelessly connected to the Zoom platform and simultaneously shared on the Zoom screen with students. It seems technology has just changed the shape and format of my class board.

Afterwards, a screenshot from the page (a photo from the teacher's new board) was shared with them on Google Drive where all the students already had access with the aim of their virtual/online engagement, collaboration, and interaction with each other during the live science session. Students also owned and utilized new boards on Google Drive, Google Jamboard, to collaborate or to individually participate in problem-solving and other activities during the live session. The beauty of technology here is how it emulates a real classroom; I had access to their boards from my side too. This new technology offers extraordinary opportunities for enhancing both students' motivation and engagement in learning and the teacher's teaching experiences. Christopher J. Dede, Jeffrey Jacobson and John Richards at the Harvard University Graduate School of Education emphasize that the goal is "to push forward the evolution of next-generation immersive learning experiences" (Dede et al., 2017, p. 2). I believe that there is a reciprocal relationship between students' *engagement* and immersive learning in science education (Anderman & Dawson, 2011).

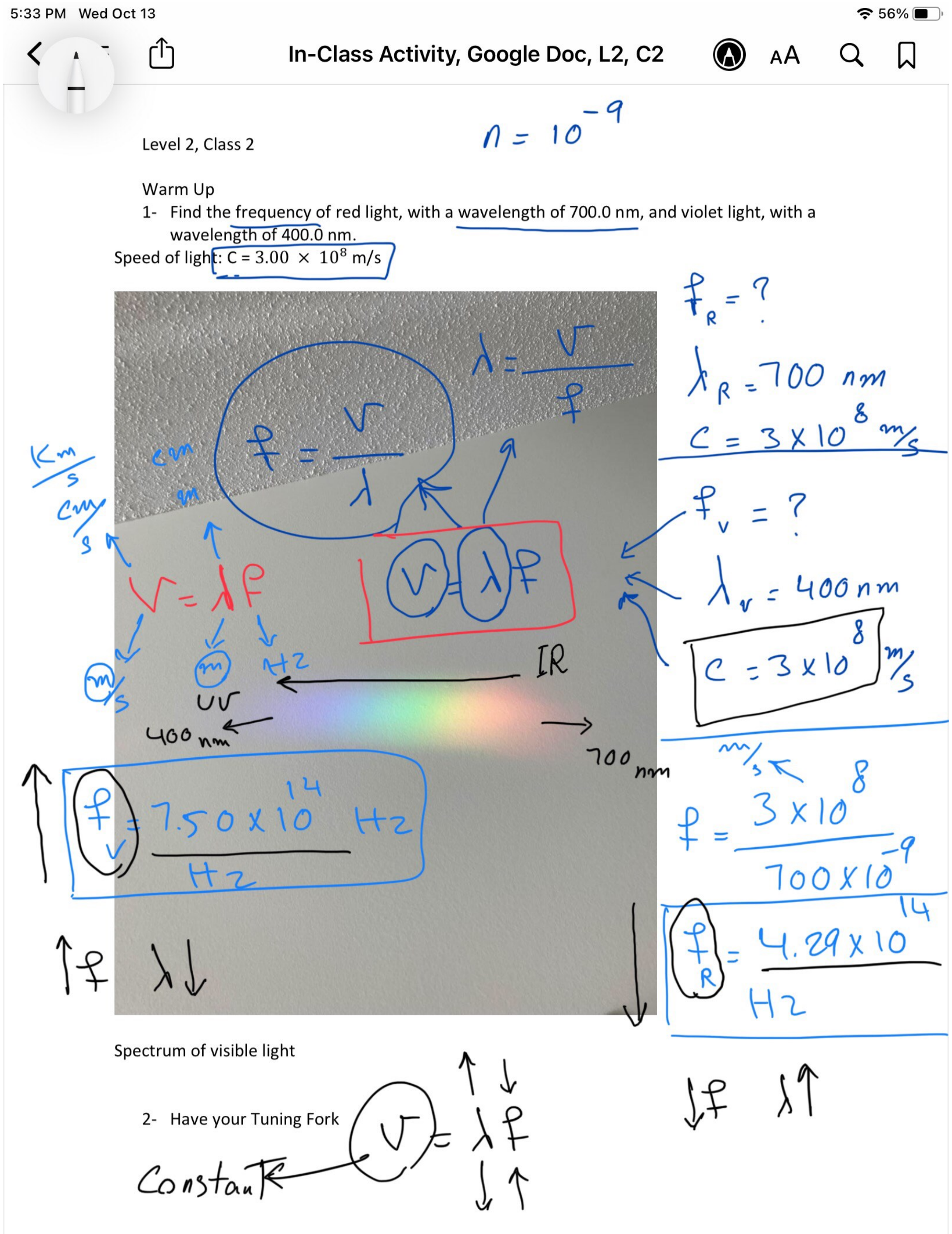


Figure 5.6 A Screenshot from a Warm-up Question Solved and Written by Myself on an iPad with an Apple Pencil While Wirelessly Connected to and Shared on Zoom Screen with Online Students.

Indeed, this is the era that technology, digital devices, and online platforms scale innovative teaching with new pedagogical approaches (Sancho, 2009; Liu et al., 2017; Milner-Bolotin; 2017a) during a critical time. For instance, a teacher can convert a *lesson plan* directly and practically into a *pedagogical means* for online teaching and students' virtual learning. In conventional education, a teacher carefully creates a lesson plan in advance, for his or her own use, as a *reference* or *guide* for teaching during the class time. However, this lesson plan can be directly shared with students and utilized as a useful *pedagogical tool* in online teaching via Google Doc or OneNote page, enabling both the teacher and the students to interact, collaborate and simultaneously work together on the resource. We, teachers, educators, curriculum designers, and administrators, should not forget that the main aim is enhancing students' learning and optimizing their experiences in the process of learning (Hamilton & Duschl, 2017; Sancho, 2009).

This resource—*lesson plan*—can be designed in various ways for responding to the lesson's learning goals. The teacher can design it by mentioning the lesson's topics and steps, including the inquiry questions (Minner et al., 2010), emphasizing activities in order, granting a time set for each part or section with clear students' tasks notes as well as providing all the other required details like links to useful educational and instructional videos and websites. Consequently, the teacher's *lesson plan* is developed for a direct and *practical pedagogical means* to demonstrate the flow of the lesson in virtual teaching to support students' online learning.

One of the best educational and instructional resources for students as well as teachers that meets the objectives was found at Stanford University. I not only learned from but also utilized the outstanding resources created by Dr. Deborah Scherrer, Director of the Stanford Solar Center at Stanford University. Her resources include the required concepts, topics, and descriptions, with many descriptive videos, photos, animations, and hands-on activities and are heavily updated with and drawn from "the excellent *Exploring Magnetism Lesson Series* developed at UC Berkeley's Center for Science Education," the US National Aeronautics and Space Administration (NASA), and the Stanford Solar Center. Scherrer (2020) states that these resources were "initially developed as a hands-on high school teacher workshop to be given in Developing Nations where resources relating to the Sun were often not available" (Scherrer, 2020). This is the science that "theoretical models are adjusted to students' world and therefore have a meaning for them" (Izquierdo-Aymerich & Adúriz-Bravo, 2003, p. 40). I had to go through the resources and first update myself and my pedagogy. Then, with having all these objectives in my mind, select, edit, and create the needed instructional and educational resources for 8th and 9th graders in the program. Undoubtedly, Dr. Scherrer's comprehensive online, free resources with valid and coherent scientific content acted not only as a guide and a legitimate teacher resource but also became an indirect teacher workshop during the lockdowns. Actually, it became my first professional development experience (Luft & Hewson, 2014; Levin, 2010) during the quarantine in 2020, albeit a virtual and self-directed one.

5.2.1. Teacher Distance Learning to Protect Educational Opportunities

This section provides a review of my learning, relearning, reskilling, upskilling, and subsequently adapting to new approaches and changes in teaching physics. How could I update my pedagogy as well as the SCP's curriculum during the quarantine and lockdowns? Teaching challenges were multifaceted, calling on a range of instructional skills and leadership decisions as well as compassion (for helping students) and passion for learning and updating oneself, which MacKinnon (2013, 2016) argues about in "The Heart of Learning," and "The Heart of Teaching." I will refer to distance learning (Perraton, 2010; Robinson & Latchem, 2004) and virtual educational and professional development (Borko et al., 2010) during the pandemic and how technology supported me and my plans. As Milner-Bolotin (2017a) emphasizes, technology has had a significant effect not only on students' learning and engagement in STEM but also on teachers' professional learning practices.

According to a document from the Organization for Economic Co-operation and Development (OECD), "A framework to guide an education response to the COVID-19 Pandemic of 2020," Fernando M. Reimers, Global Education Innovation Initiative at Harvard Graduate School of Education and Andreas Schleicher, Directorate of Education and Skills at OECD, strongly believe that "cooperation can assist education leaders in devising effective education responses, and that the first and simplest form of cooperation is to exchange knowledge about what schools, communities, and countries are currently doing to protect educational opportunities during the pandemic" (OECD, 2020C, P. 4).

They offer a progressive and inclusive checklist with the aim of supporting and directing the progress of education strategies during COVID-19. Schleicher and Reimers not only shed light exactly on my own wishes as an instructor and a director in planning “effective education responses” in my designing a science program but also on the needs of all education leaders, educators, and teachers around the world during the pandemic. They assert that the key aim of this framework is to support and encourage a “process of exchange of knowledge” to develop and implement effective approaches in any context of education (OECD, 2020c). They indicate the moments that I was striving to explore the most updated and adapted educational, instructional, and pedagogical strategies in teaching and learning physics online via virtual platforms with various digital technologies—technology-based solutions.

Indeed, such *cooperation* and *exchange of knowledge* was immediately initiated by educators across countries during the pandemic. I myself have spent more than fifty hours in national and international webinars, events, conferences, workshops, and professional development in North America and Europe since 2020. The constructive effects of this professional development have already been demonstrated by the result of studies (Milner-Bolotin, 2017a; Desimone, 2009, 2011). For instance, helpful tips, strategies, and approaches were shared, exchanged, and developed between educators and teachers throughout various events and resources online. Innovative and creative approaches emerged from the gaps and challenges too. American and Canadian universities and associations played key roles in leading, guiding, and supporting educational affairs as well as offering online and virtual learning opportunities and solutions in various contexts, which helped “guide the development of context-specific education strategies” in the field of physics (OECD, 2020c, p. 4) during the pandemic. In sum, countries with their *cooperation* and *knowledge exchange* protected educational opportunities during the global crisis of COVID-19, as emphasized by Schleicher and Reimers (OECD, 2020c).

5.2.2. Adapted and Updated Curriculum and Pedagogy

In this section, I explain how I adapted and updated not only myself (my skills and knowledge) with the high-paced changes but also with the physics curriculum designed for a science program and the pedagogical approaches and tools utilized for teaching and assessing adolescents’ physics learning in SCP since 2020. It is significant that the goal was to create a curriculum which would allow students to have the experience of a general liberal education connected to contemporary knowledge and 21^{st}-century required skills. This would enable them to effectively understand and explain some of the fundamental scientific and relevant natural phenomena to contemporary life while experiencing scientists' science with scientific methods and contemporary tools (Izquierdo-Aymerich & Adúriz-Bravo, 2003). To sum up, I illustrate how we—educators, teachers, and students—could positively adapt ourselves to the current changes while appreciating reforms with all their challenges and regard them as new opportunities towards a better education (Hargreaves et al., 2010; OECD, 2020c; OECD, 2021b; Schleicher, 2020; Schleicher et al., 2021).

I wish to shed light on a general liberal science education in which not only teachers can freely work and use their autonomy (Reimers & Chung, 2019; Erss, 2018; Lamb, 2000) to vigorously create something but also students are free to demonstrate their learning (Shernoff et al., 2003) and innovation (Reimers & Chung, 2019; Schleicher, 2018) without the stress of exams or assessment tests. I believe that autonomy and freedom for both students and teachers are two imperative factors in having creativity and innovation (Reimers & Chung, 2019; Schleicher, 2018). I as an educator wish to advocate for *intellectual freedom* and the project of *intellectualization* which was discussed by Pinar (2019). I wish to depict facilitation of the intellectual conditions in a science classroom in this chapter. Of course, there were moments that I could mobilize myself to act in very complicated situations, to turn against the "anti-intellectual conditions," and to create opportunities for students' creativity and individuality, not primarily test-taking skills. I strongly believe, as argued by Pinar (2004, 2012, 2019), that these views and endeavours are necessary approaches for experiencing a liberal science education in the 21^{st} century. Therefore, if students can avoid the stress of exams, then how could their learning be assessed in a liberal science education in the 21^{st} century?

5.2.3. New Contemporary Assessment

By transforming and updating curricula and a pedagogical approach in learning and teaching physics in SCP, students' assessment cannot remain unchanged, from my point of view. Assessment needs to be updated and adapted too. In this section, I rethink students' science learning assessment in SCP and attempt to align it with the adapted curricula and pedagogical approaches in the program. In this revolutionized approach, there are no final exams, summative assessments, or report cards. However, we do assess students' progress in some completely different ways. We teachers make it possible for students and parents/guardians to track the progress of learning. We do this in a way that is feasible and convenient for students throughout the virtual environment during COVID-19. Since the pandemic, we have received support from technology, the digital environment, and an online connection, interaction, and collaboration. This assessment will be done in a way in which students will have adequate time and will be free to complete and submit it online.

The Student Assessment will be composed of the following steps:

1- Homework submission on an online platform.
2- Self-Assessment Form (SAF) completion for every two classes; therefore, for every 10 classes, five SAFs must be submitted online.
3- Five Video Recordings. Every student needs to create five videos individually.
4- Group Work: Collaborative Project (CP).

With regard to videos, students are free to choose any topic on which they would like to create videos. Moreover, they will have access to lessons and resources during their work. Therefore, for the aim of letting them demonstrate their learning, creativity, and innovation in the current level and being able to advance to the next level in the program, students are assigned to make five videos of experiments or demonstrations. They are expected to select their topics from the lessons and the materials provided for the lessons on the online educational platform. However, students are encouraged to make more videos, as many as they can, to demonstrate their knowledge and skills in science investigation. They can present and discuss a topic, concept, or lesson in their videos. They do not have to necessarily conduct a demonstration in all of the videos. We welcome any creativity and innovation that they bring into their videos.

Regarding CP, project-based learning, every group of three will choose a topic or concept which has a problem-solving question and a demonstration. That is, a topic is chosen, and a question related to that topic should be asked that requires solving and conducting an experiment or a demonstration. Students inform the instructor of their topic and what their plan is. Three students need to work together collaboratively. One of them discusses and presents the concept of the topic, another student solves a problem/question about that topic/concept, and the last person conducts an experiment or demonstration related to the concept and topic. Each student should record themselves individually. Students need to share and check each other's work. For example, the person who creates the demonstration video should check the concept-presentation and discussion video, and the student who creates the problem-solving video should check the demonstration video. Finally, the student who creates the concept-presentation video will check the problem-solving video. Figure 5.7 illustrates the cycle, and the way that students would accordingly collaborate:

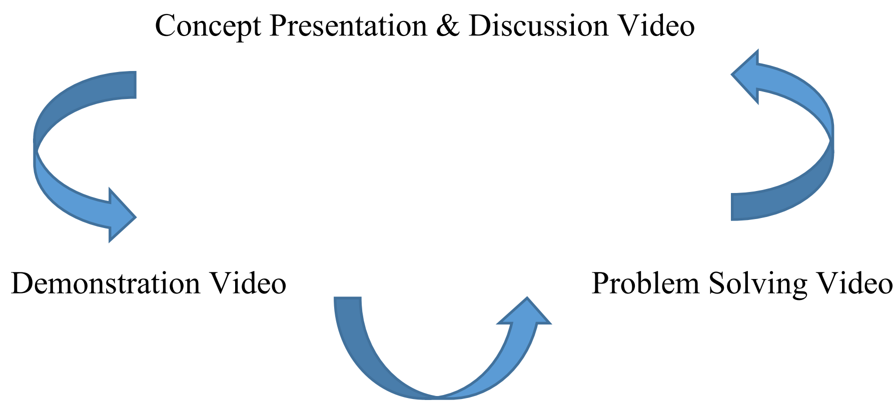


Figure 5.7 Cycle of Students' Group Work and Collaborative Project for Recording a Comprehensive Video Consisted of Concept Presentation and Discussion, Demonstration, and Problem Solving in the SCP.

When all three students agree on the correction and completion of the contents of the videos, they need to finalize it with the instructor before combining the videos. In the end, students must add and combine all their individual work and recorded videos into one final video. Therefore, each group should submit a video consisting of three parts: 1) discussing and presenting a concept; 2) solving a problem; and 3) demonstrating an experiment. To sum up, these three parts create a unique work of the students' collaboration. Students who successfully complete the four assessment steps will be celebrated as an *Active Young Scientist* in the program to enhance their participation and enthusiasm in science.

The following is a real CP example in physics. For instance, for the topic of quantum mechanics, the Young's double slit demonstration:

1- One student records a video about the double slit experiment while playing with the PhET simulation, Quantum Wave Interference. The concepts will be discussed and presented by the student in the video.

2- One student chooses one of the questions/problems related to the double slit phenomena provided in the lesson materials/resources (handout, worksheet, lesson PowerPoint, and so forth) and solves it while recording a video of the process and the steps of solving of the problem. The student can write and solve the question on a piece of paper and record a video of the work.

3- Another student records a video of performing the experiment of the double slit with laser and the provided sheets of printed slits at home.

4- Students need to combine all three videos together and create one final video consisted of discussion, demonstration, and problem-solving.

Why do I propose to assess young students in this way in science? The National Science Foundation in the US states that “the innovators also changed their assessment and grading practices to align with this emphasis on project-based learning” in STEM (NSF, 2020, p. 22). Our education, work, and actually, our lives in the 21st century have truly and strongly been interwoven with technologies. Besides all the goals for their learning, students are required to develop skills to enable them to make real progress towards success and achievement, not only in their education but also in their lives and future careers (NSF, 2020, 2008; Natural Sciences and Engineering Research Council of Canada, 2021, 2010; Science, Technology and Innovation Council, 2015; DeCoito, 2014, 2015b, 2016; Schleicher, 2018; OECD, 2021a, 2021b, 2020b, 2019b; Milner-Bolotin, 2017a; Beers, 2011; National Science Foundation, 2020, 2008; Council of Canadian Academies, 2015; Schwab & Davis, 2018). These skills are as follows:

- Active Learning
- Problem Solving
- Critical Thinking
- Innovation
- Creativity
- Analysis
- Technology Use
- Technology Design
- Reasoning
- Collaboration

During this pandemic and our shift towards online learning, having students create a video is a way to motivate them in the field to do something interesting with technology and the lessons provided and taught to them. The World Bank (2020) underlines the significant role that videos play in students' online learning during the pandemic. Their video reflects their understanding, learning, reasoning, innovating, creativity, and ability to solve and analyze while they are using technology and improving their self-confidence. In the end, in addition to engagement and participation in the class activities, each student is assessed not only according to group work and the collaborative project but also independently according to their own chosen topic (not the imposed one) and interest, and the created video—performance-based assessment as emphasized by NSF (2020).

5.2.4. Curriculum Transformation and Big Ideas

It is important that one of the key goals of this study is to focus on curriculum change (Schwab, 1969) with big ideas interwoven with contemporary scientific issues (Blades, 2021; Tyler, 1949) and let us adapt and reform our inclusive pedagogy (Barad, 1995) while utilizing updated pedagogical tools for diversion of the theoretic to the practical in science (Schwab, 1969; Dewey, 1916, 1929). As such, I have found two substantial points in common with David Blades, Professor of Science Education and Curriculum Studies at the University of Victoria, and resonate with his views. First, in "Beauty in the Shadows: Curriculum Change and the New BC School Science Curriculum," Blades, with the help of *light phenomena* and creation of shadows due to the existence of different obstacles (which would create/cast various shadows), examines the "development of the new school science education curriculum in the province of British Columbia in Canada." Second, through autobiographical inquiry, he proposes an alternative approach "to conceptualize curriculum change" (Blades, 2021), applying Pinar's method of *currere*. He points out and emphasizes "the beautiful possibilities that exist within the patterns of shadows cast by strong light" (p. 1). He illustrates how obstacles in science education in Canada, in light of the American science education influence, could cast and create subtle and beautiful shadows of possibilities and opportunities to conceptualize curriculum change—a transformation in science curriculum.

Indeed, Blades utilizes the concept of light and shadow as a metaphor in science education in Canada. He demonstrates how the new BC science curriculum in Canada, with lingering shadows of the obstacles in science education and the light of the American new science curricula (post-Sputnik program, STSE science education, and STEM) could utilize the dark shadows as new possibilities and opportunities for a change towards more progress in science education instead of "resisting or trying to overcome brightness" (p. 1).

From one perspective, the rhetorical aspect of shadows, as Blades mentioned, can represent fear, darkness, danger, lack of clarity, incompleteness, error, coldness, evil, ruin, doubt, and ignorance. In English and Euro-centric perspectives, "Shadows are almost always considered as negative rhetorical metaphors" (Blades, p. 12). However, from another perspective, the physical concept of shadows, as Blades utilizes in a practical way, can create beauty and opportunity: The beauty that we see in nature; the joy of tranquillity and the opportunity and possibility of enjoying the long shadow of a huge obstacle; the opportunity for tranquillity and calmness after a long shadow has been created by a huge obstacle under the burning conditions of a light source in a complicated situation. All are a metaphor for science curriculum in Canada under the light of the USA's curriculum reform. Blades beautifully refers to shadow as a place in time—in a shadow of something or under a shadow of something, why does time matter? The duration of being in that particular place is important.

Coming out of/from the shadow of American influence and entering or coming into the light of the "newness" and "illumination," with new opportunities for science curriculum in BC, Canada, is attempting to escape the long shadow cast by major post-World War II reforms in science education. However, Blades argues that coming out of the long shadow of the post-Sputnik reforms is challenging for Canada. As such, he (2021) utilizes Pinar's autobiographical method of *currere* by first returning to the past and the history of the science curricula (the regressive moment) when the pedagogical approach of post-sputnik science is also problematized by Barad (1995) due to its patriarchal and gendered approaches in physical science, and second, foreseeing and aiming toward the future of science education (the progressive moment).

Blades refers to science curriculum history and how the former Soviet Union's technological successes in aerospace (aeronautics and space) and nuclear weapons design stimulated the United States to change their science education curricula in educational institutions, aiming to create excellent scientists by studying the three fundamental disciplines of biology, chemistry, and physics. It was significant as the US could not educate and train an adequate number of scientists and technologists in comparison with the Soviet technological successes and innovations in its time (Blades, 2021, p. 3). Therefore, this resulted in full support and funds provided for school science education from the US Department of Defence, the National Science Foundation, and the National Aeronautics and Space Administration.

These new science programs in schools utilized “new textbooks, lesson plans, films, and kits of materials” (Blades, 2021, p. 3). As such, some countries like Canada, with the same concerns about the Soviet Union’s technological improvements, tried to conform to these curricular changes and embraced the American new science programs in the schools. In fact, not only were the educational materials directly imported from the US to the Canadian school systems, but also, as Blades believes, “a long shadow on curriculum development in Canada” (p. 3) was cast by the influence of the American new science curricula. However, such financial support in the US did not happen in Canada (Blades, 2021).

Canada, after conducting a four-year study of science education, decided to give authority to each province to create and “develop their own school science programs that reflected their history, geography and environments—in essence, escaping the shadow of the American post-Sputnik reforms by creating the bright light of a uniquely Canadian science curriculum” (Blades, 2021, p. 4). However, as asserted by Blades (2021, 1997), in addition to some Canadian examples, only the order of the topics in the science curriculum changed. Blades claims that this issue was related to the agenda of curriculum change which was still looking at “producing scientists and technologists to ensure a national advantage in a global economy” (p. 5). Consequently, this view demonstrates that Canada either altered her political, social, and economic goals in the world as well as the educational purposes or remains concerned like the US. This perspective reveals that Canada was no longer concerned about any countries being a threat since she was pursuing a science education which is “not for producing rocket scientists, not a reproduction of its own kind, but for securing the continuation of the human species, a turn towards a science literacy that takes seriously our positioning and responsibility to other species' survival" (p. 5). Canada, though, is still continuing to adopt America's approaches in science education.

Indeed, this new perspective in science education leads towards and results in a citizenship approach to science which reflects the interdisciplinary relationships between science, technology and society—"Science-Technology-Society" (STS) approach—as emphasized by Blades. Afterwards, this approach embraces "environment" in its educational consideration list, STSE (Science-Technology-Society-Environment). Blades affirms that this science curriculum

> could be truly Canadian, a move out of the shadow of the post-Sputnik reforms based on international competition towards the light of a science education that was for all students, a citizen-based science education that could help students develop the attitudes and skills to deal with the social and environmental consequences of technological and scientific innovation. (Blades, 2021, p. 5)

He points to the nature of science and the beauty of science as well as the importance of its social aspects in an STSE approach of the Pan-Canadian Framework recommendations while the American Association for the Advancement of Science and the US National Research Council still underlines the importance of high-quality instruction, content of science curricula, and high-level assessment tests (Blades, 2021; Marx & Harris, 2006). Blades indicates that in 2012, the US aimed towards economic superiority and economic leadership instead of competing with the Soviet Union (Blades, 2021; 2020), which again resulted in more focus on practical science education and content learning in not only science and technology but also mathematics and engineering (STEM). Therefore, the new STSE approaches to science education in the US and Canada faded out, and only the science and technology aspects of these approaches remained in science education.

The Canadian educational systems remain in the long shadow of the American curriculum reforms with the agenda of STEM approaches in addition to the agenda of the post-Sputnik reforms in science education (Blades, 2021). As such, the province of British Columbia in Canada creates a unique and new curriculum that embraces all the aforementioned approaches in science education—including the content knowledge of the post-Sputnik US curriculum reforms, STSE, and STEM (Blades, 2021). Why did BC attempt to revise science education in the province? Indeed, why does Canada attempt to create different curricula in science education? What aspect of science learning is being attentively considered most in the New BC Curriculum? It is significant, as explicitly emphasized by Blades (2019), that “19th and 20th century models of learning and teaching was no longer valid in the 21st century, particularly due to the rapid development of digital applications” (Blades, 2019, p. 24). There is a need for a curriculum that “would truly prepare students for the challenge of citizenship in the 21st century” (Blades, 2021, p. 10) and would help them acquire the required knowledge and skills.

The fourth industrial and technological revolution requires 21st century curricula and approaches in science education as I discussed in this study. These approaches should be updated and adapted not only to the Fourth Industrial Revolution but also to career paths and job markets in the future (Schwab, 2016; WEF, 2020a, 2020c). The issue of being outdated and having poorly adapted curriculum to the Fourth Industrial Revolution was vigilantly detected by the BC educational system in 2015.

> Today we live in a state of constant change. It is a technology-rich world, where communication is instant and information is immediately accessible. The way we interact with each other personally, socially, and at work has changed forever. Knowledge is growing at exponential rates in many domains, creating new information and possibilities. This is the world our students are entering. British Columbia’s curriculum is being redesigned to respond to this demanding world our students are entering. (BC Ministry of Education, 2015, p. 1).

BC, while lingering under the shadow of the US curriculum reforms, could develop a new revolutionized science curriculum which “helps students develop the intellectual, personal and social skills for success in and beyond schooling through the foundational competencies of communication, thinking and personal and social competency” (Blades, 2021, p. 10). From the perspective of David Blades and the New BC Science Curriculum, this appears to be a sound rationale for the aim of having educated citizens in society.

In the New BC Curriculum, in fact, there are four important factors as mentioned by Blades (2021, p. 10): 1) limiting the prescribed curriculum; 2) ensuring a concrete application on essential learning and big ideas; 3) flexibility and choice for students and teachers; and 4) 21st-century forms of assessments. These four factors can not only increase students’ interest, intellectual motivation, and participation in science but can also help students “to understand the processes of science, the skills, attitudes and limitations of science as a human activity" (p. 11). This approach can make science the students' choice and preference as a subject as well as a future career and gives teachers the autonomy to teach science in a way that reflects their beliefs and their pedagogical content knowledge (Blades, 2021). I believe that, with this reformed and updated curriculum, both teachers and students are free to fluctuate (to teach and learn) in the fluctuation of curriculum and content knowledge between the examples (big ideas) of science, like a water wave, or more scientifically like light waves, to lighten the ideas, innovation and creativity that they are intellectually interested in and engaged with in science education since there is "nothing linear in the approach to curriculum reform" as claimed by Blades (p. 11). We—teachers, educators, and curriculum developers—in light of curriculum change, should lighten students' learning paths, and provide them with more enjoyable and efficient learning experiences in science.

Therefore, for the aim of creating that characteristic science curriculum focussed on the *big ideas* while constructing a proper infrastructure for learning the most recent relevant scientific problems and *scientists' science*, I referred to the universities' website-based activities, resources, and events in the US and Canada, such as University of Colorado Boulder, Texas State University, and the University of Waterloo, as well as their scientific centres like the National Aeronautics and Space Administration (NASA), Perimeter Institute, and their relevant STEM education events. It is significant that these scientific educational and technological hubs immediately and carefully acted to develop applicable STEM education responses and protect educational opportunities for everyone during the crisis of COVID-19. For example, NASA, Texas State University, Perimeter Institute, and University of Waterloo educators and specialists created and shared high-quality STEM-context resources that are free and easily accessible materials including worksheets, guidance, hands-on activities with complete instructions, and educational and scientific videos and events. They are experts in easing the language of science for students as well as creating and simplifying for them the scientists' methods and objectives—scientists' science. This is an approach that has been emphasized by scholars in education (Izquierdo-Aymerich & Adúriz-Bravo, 2003). Not only do they support teachers and educators now, but could also engage students during and after the pandemic and introduce them to STEM content with thrilling STEM contexts from the scientific centres.

Free and authentic NASA educational resources and webinars on STEM education topics are available to all educators, teachers, and students at all levels. Informal educators, pre-service educators, pre-service teachers, K-12 teachers, K-12 educators, and university faculty all can benefit from the educator professional development collaborative (EPDC) events at NASA STEM EPDC. This is an unprecedented learning opportunity (for educators and students) of NASA's explorations and discoveries while connecting with NASA people and facilities to better understand NASA's mission and work, scientists' science. Izquierdo-Aymerich & Adúriz-Bravo (2003) called it *didactical intervention*; that is, it is necessary to have scientists' scientific experimentations and scientists' language in our science classrooms, but a simplified version. If this simplification was being done by expert educators and education specialists who are in close contact and connection with scientists, the resources would positively respond to students' learning and teachers' teaching needs. This is exactly what I explored and experienced myself with the University of Waterloo events, professional developments opportunities, and resources created by their educators in contact with the quantum scientists in Canada. Furthermore, the teachers should be free to transpose the scientists' science while they stay profoundly connected to scientific knowledge (Izquierdo-Aymerich & Adúriz-Bravo, 2003). Therefore, to design quality science curriculum, I preferred embracing the NASA STEM education and the Perimeter Institute specialists-created resources to bring not only *scientists' science* but also *scientists' contexts*—NASA STEM contexts and Perimeter Institute Quantum Physics contexts—into students' STEM and quantum mechanics content learning and let them experience and practise the exciting and unique hands-on activities and virtual resources of scientific hubs.

Furthermore, the other helpful and utterly reliable, free, interactive, and easy access online physics resource is none other than *Physics Education Technology (PhET) Interactive Simulations* from the University of Colorado Boulder (PhET, 2021; McKagan et al., 2008). From my point of view, the roots and resources of the big ideas can be mostly explored in the physics PhET simulations and their related teaching and learning resources embracing activities not only for teachers' teaching but also for students of various age levels learning on the PhET website. The PhET Interactive Simulations project was founded by Nobel Laureate Carl Wieman at the University of Colorado Boulder in 2002. It is significant that PhET simulations are developed and based on education research which has enhanced students' engagement "through an intuitive, game-like environment" where students can either independently or collaboratively learn through investigation and observation (PhET, 2021; Buckley et al., 2021; McKagan et al., 2008; de Jong, 2011). Most of the simulations have been designed in a way that students initially can independently start working with them and explore the variables and values of the concept by changing various quantities and options provided in the simulation screen like a real experiment and demonstration but at their own pace, in their own place, and on their own time.

PhET simulations support education curriculum and curricular needs as well as pedagogical approaches (Chotimah, 2021; Mahtari et al., 2020; McKagan et al., 2008). With the help of technology and digital devices (Sancho, 2009), each simulation can be converted to various curriculum materials and curriculum contents which can be simultaneously utilized as a pedagogical means for teachers teaching and students learning. For instance, by taking screenshots while exploring and running the simulation in different features or conditions, a teacher can create instructional resources by inserting some instructional and conceptual notes, statements, or formulas required for teaching or even for students' inquiry-based practices (Minner et al., 2010). Indeed, simulations, for some complicated topics, can beautifully visualize (de Jong, 2011; Mayer & Alexander, 2011, 2016) phenomena and all the concepts behind them more effectively than a real demonstration in a physics lab while letting the students independently play with and explore the concepts (PhET, 2021; Buckley et al., 2021; McKagan et al., 2008). For example, if I refer to the concepts of waves interference, wave-particle duality, and Young's double slit experiments in quantum mechanics, I believe that the majority of both teachers and students would acknowledge that PhET simulations visualizations are a great help in their teaching and achieving the learning goals in quantum physics (Yulianti et al., 2021; Faletič & Kranjc, 2021; McKagan et al., 2008; Zollman et al., 2002).

In Figure 5.8, we can see the original and a clean web page of the Quantum Wave Interference PhET simulation without any annotations. It is important as instructional annotations and notes will be purposefully added to the photos taken from the simulation's screen in the next figures.

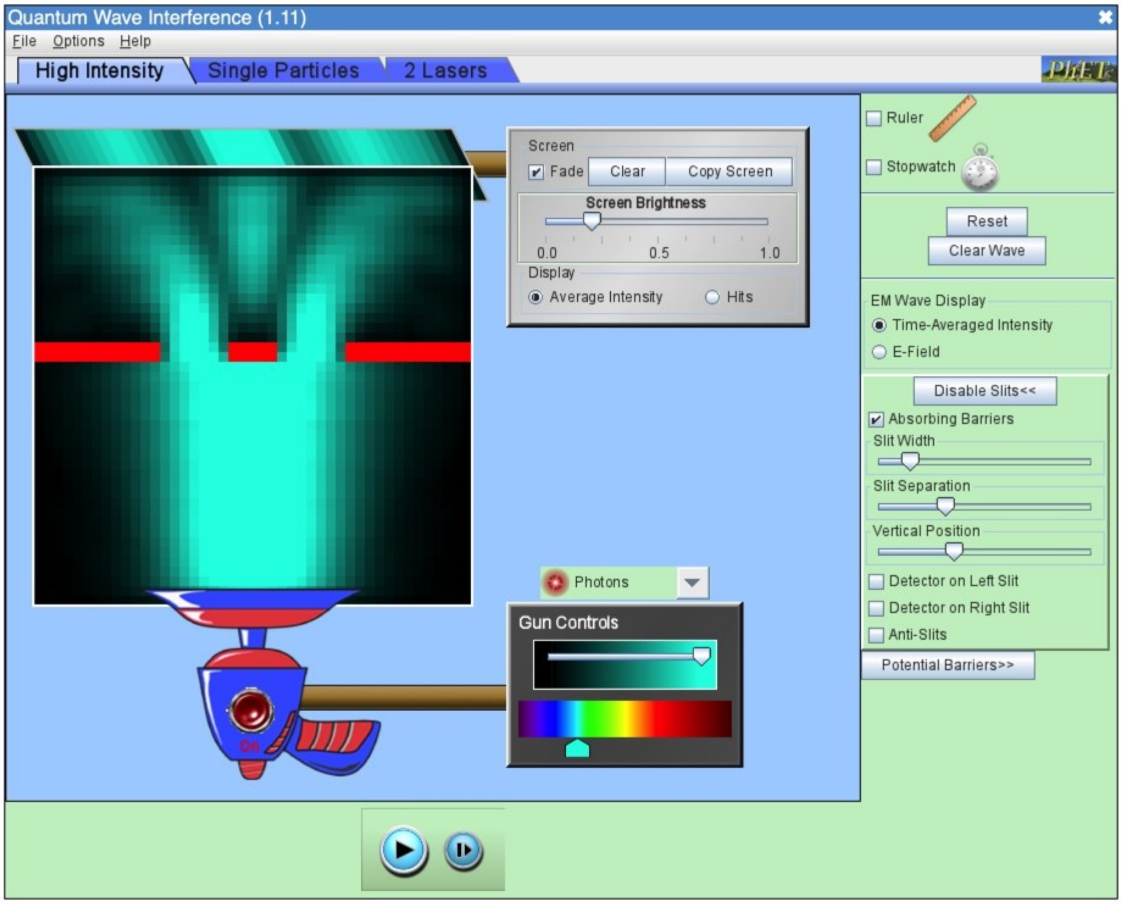


Figure 5.8 PhET Simulation, Quantum Wave Interference, High Intensity, Double Slit Demonstration, an Original and Clean Screen of the Simulation on the PhET Webpage, 2021.

Figure 5.9 shows how PhET simulation can visualize and illustrate the behaviour of light (photons), wave-like behaviour of photons as well as their particle-like behaviour—Wave-Particle Duality—while technology and our digital devices help us create a shareable educational resource when we add our notes and comments on the simulation.

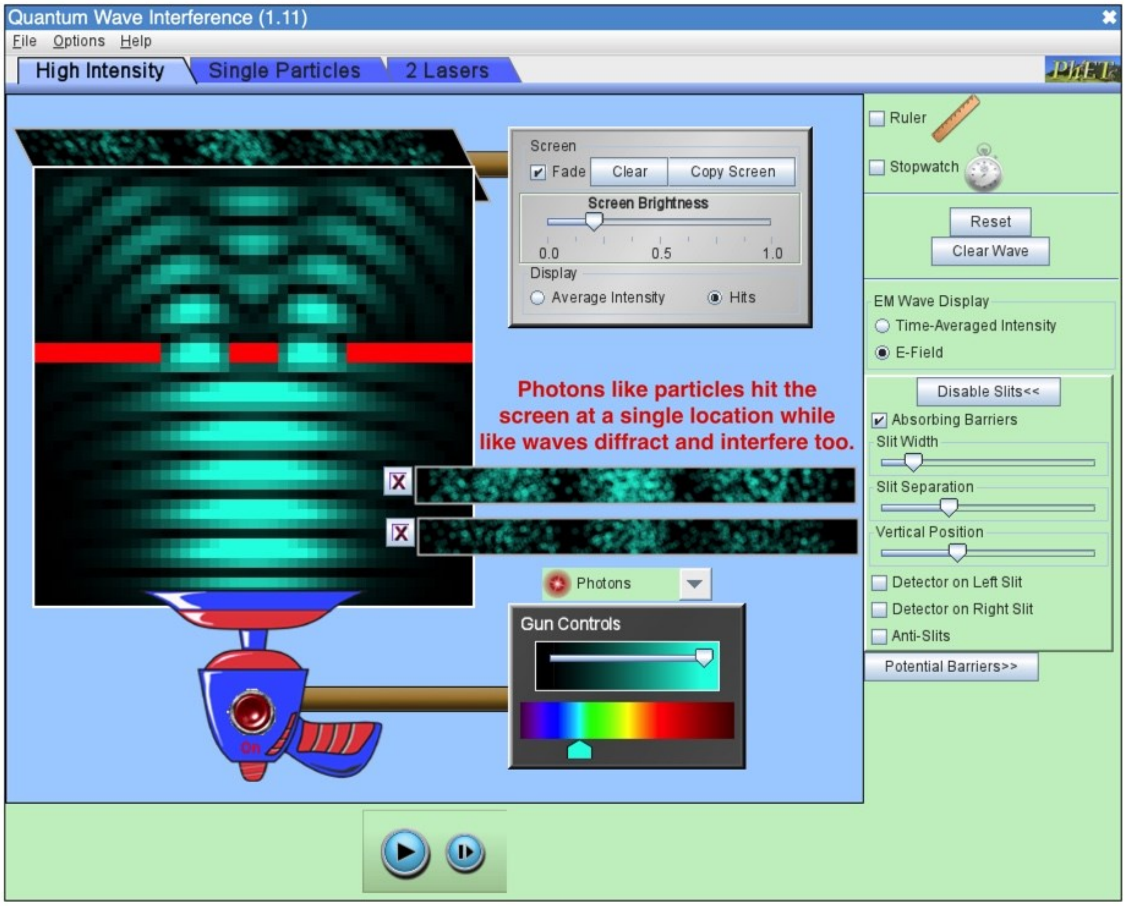


Figure 5.9 **PhET Simulation, Quantum Wave Interference, High Intensity, Double Slit Demonstration, Wave-Particle Duality, Photons.**

This figure is a screenshot from the PhET simulation with some instructional red annotations that I added for students' learning. The simulation let the students independently explore (de Jong, 2011; Day & Goldstone, 2009) the behaviour of not only photons (light particles) but also the behaviour of the other subatomic particles and quantum objects like electrons, neutrons, and helium atoms (Figure 5.10) when passing through the slits (openings). This is not an easy experiment for high schoolers outside a physics lab. However, PhET simulation beautifully visualizes the particles' wave-like behaviour as they go through both slits though they are particles and hit the screen at a single location. In short, PhET simulations make understanding of one of the most complicated and hard to imagine concepts easy and tangible not only for students but also for science teachers.

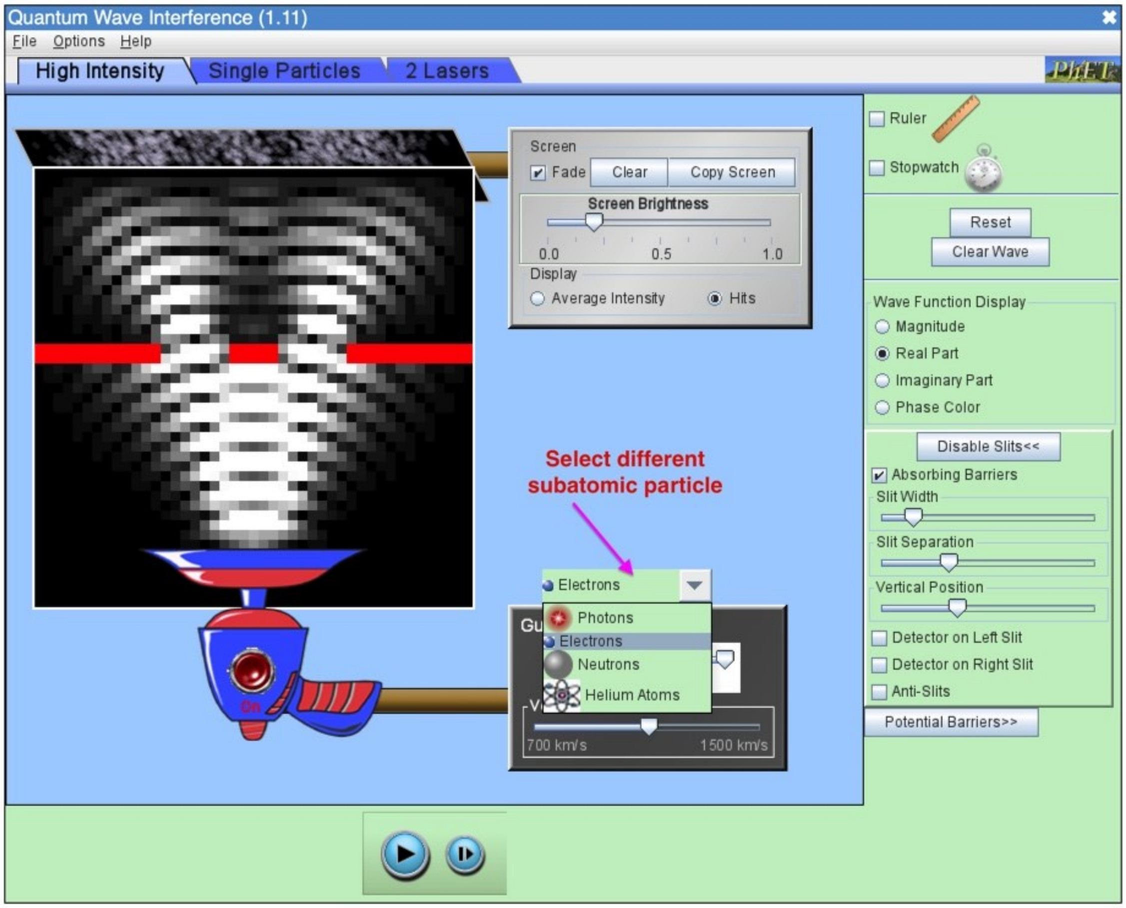


Figure 5.10 PhET Simulation, Quantum Wave Interference, High Intensity, Double Slit Demonstration, Wave-Particle Duality, Electrons.

Simply visualizing (de Jong, 2011; Mayer & Alexander, 2016) the particle-view of light and wave-view of quantum objects (particles) is an important step towards simplifying and easing learning of quantum physics. My observations affirm how students and even science teachers, without a background knowledge in the field of physics, experience difficulty in understanding and imagining the principles and theories of quantum mechanics (He et al., 2021). Wave-particle behaviour of light and quantum objects is not something that can be easily imagined and conceived by students from the actual experiment itself (Olsen, 2002; Duit et al., 2014; Müller & Wiesner, 2002). It needs a profound analysis and understanding of quantum mechanics and the related fundamentals (Baily & Finkelstein, 2009). One of the reasons that adolescents could successfully progress their learning from waves principles to quantum mechanics is the significant effectiveness of the PhET simulations on both curricular resources as well as the pedagogical approaches utilized for students' physics learning (Yulianti et al., 2021;

Faletič & Kranjc, 2021; Baily & Finkelstein, 2009; McKagan et al., 2008; Zollman et al., 2002). It is a great method for teaching and learning physics concepts and heavily supports students' content learning in physics (Yulianti et al., 2021; Faletič & Kranjc, 2021; Chotimah, 2021; Mahtari et al., 2020; Baily & Finkelstein, 2009; McKagan et al., 2008; Zollman et al., 2002).

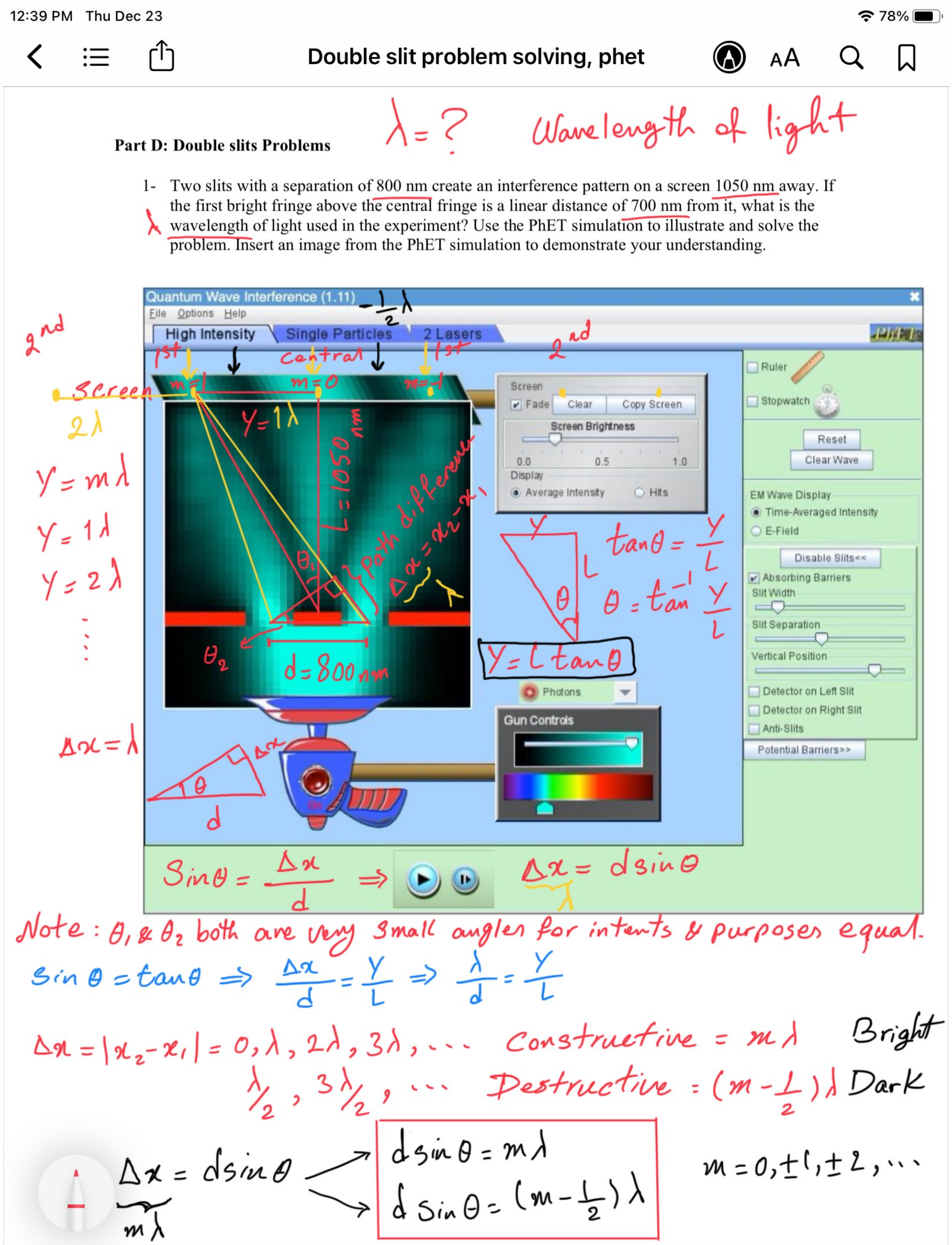
Therefore, PhET simulations as a *virtual physics lab* are great to support students' learning either during the individual activities or group work activities which can independently and collaboratively engage students during the online and in-person class. This could be very useful for young students' active participation and active learning during online classes and replace the practical hands-on experiences they could have in a real physics lab and with simulations as a virtual physics lab. To sum up, PhET simulations could significantly increase the efficiency of an online teaching environment for physics classes during the lockdowns and school closures of the COVID-19 pandemic though they were effectively being used before this crisis too (Fox et al., 2020).

Designing and preparing the curriculum content learning for students with simulations made education, particularly for the mathematical sciences, easier during the pandemic (Fox et al., 2020). As such, I appreciably utilized PhET resources to design the SCP's curriculum. The results of studies reveal the effectiveness, validity and practicality of PhET-assisted worksheets in improving students' critical thinking, problem solving and independent learning skills (Chotimah, 2021; Mahtari et al., 2020). At the beginning, I attempted to only use the PhET activities and worksheets which had been written either with PhET people or with other physics teachers around the world. Undoubtedly, great resources and activities had been collected for both teachers and students by PhET experts on the website. However, after a while of downloading and editing the resources, I enthusiastically decided to write my own versions of the worksheets and activities for the PhET for some specific topics encompassed in wave-quantum-curriculum. I found not all the resources were responding to my learning goals in the planned curriculum as well as the considered pedagogical approaches for teaching physics online via Zoom.

Furthermore, building and preparing students' background knowledge associated with and required for learning *waves-related concepts* towards *quantum mechanics* needed an adequate understanding of the abstract concepts and practical observation of experiments and demonstrations in a class or physics lab. However, PhET simulations helped students to virtually demonstrate and have the experience of making waves phenomena like diffraction and interference with water, sound, and finally light out of a real physics lab and in-person classroom.

In fact, teaching and learning the fundamentals of the most complicated topic and abstract concept of physics, quantum mechanics, (McKagan et al., 2008; Zollman et al., 2002; Singh, 2001) become easy and feasible with PhET simulations visualization, particularly with *PhET quantum simulations* (McKagan et al., 2008; Zollman et al., 2002; Baily & Finkelstein, 2009; Yulianti et al., 2021; Faletič & Kranjc, 2021). We are now at the heart of the heavy curriculum*, wave-quantum-curriculum,* (our cruise-ship-launching moment in water that has been designed carefully and efficiently) with being *eclectic* from a large *bulk of curriculum* and focussing on *practice* with updated technological pedagogical tools in a *deliberative* and *collaborative* inquiry-based learning setting, with help from Schwab (1969), Dewey (1916, 1902, 1929), Tyler (1949), Pinar (2019), and Barad (2007). We, teachers, should encourage students' intellectual engagement, motivation, and other positive and effective factors in their learning (Wentzel & Watkinz, 2016; Anderman & Dawson, 2011; Csikszentmihalyi, 1990, 1996; 1997; Shernoff et al., 2003) since balancing matters here (for successful flotation of the cruise ship in water, buoyant force/thrust should be equal or more than the weight of cruise).

In Figure 5.11, PhET simulation helps us understand how and why an interference pattern—fringes with various widths—are formed on a screen and how slits separation, slits width, and their vertical position from the screen can affect and alter the interference pattern on the screen. Moreover, visualization with the simulation (de Jong, 2011; Mayer & Alexander, 2016), particularly PhET Quantum Wave Interference simulation, not only can help students better understand the double slit problems and the ways of solving them, but can also support teachers teaching. Below, Figure 5.11 illustrates how digital devices and simulations (combined and utilized together) can support our pedagogical approaches in teaching and learning physics. This figure is the last screenshot from the last step out of the five steps of me solving the question on and with the PhET simulation during my teaching moments in the Science Circles' online classroom. The students were simultaneously able to engage and respond to my queries by editing and annotating on the screen via Zoom.



12:39 PM Thu Dec 23 78%

Double slit problem solving, phet

Part D: Double slits Problems $\lambda = ?$ Wavelength of light

1- Two slits with a separation of 800 nm create an interference pattern on a screen 1050 nm away. If the first bright fringe above the central fringe is a linear distance of 700 nm from it, what is the wavelength of light used in the experiment? Use the PhET simulation to illustrate and solve the problem. Insert an image from the PhET simulation to demonstrate your understanding.

$\sin\theta = \frac{\Delta x}{d} \Rightarrow \Delta x = d\sin\theta$ (λ)

Note: θ_1 & θ_2 both are very small angles for intents & purposes equal.

$\sin\theta = \tan\theta \Rightarrow \frac{\Delta x}{d} = \frac{Y}{L} \Rightarrow \frac{\lambda}{d} = \frac{Y}{L}$

$\Delta x = |x_2 - x_1| = 0, \lambda, 2\lambda, 3\lambda, \ldots$ Constructive $= m\lambda$ Bright

$\frac{\lambda}{2}, \frac{3\lambda}{2}, \ldots$ Destructive $: (m - \frac{1}{2})\lambda$ Dark

$\underbrace{\Delta x}_{m\lambda} = d\sin\theta$ $\boxed{\begin{array}{l} d\sin\theta = m\lambda \\ d\sin\theta = (m - \frac{1}{2})\lambda \end{array}}$ $m = 0, \pm 1, \pm 2, \ldots$

Figure 5.11 **PhET Simulation, Quantum Wave Interference, High Intensity, Double Slit Demonstration, Problem Solving, Annotated by Me, Solmaz Khodaeifaal.**

Indeed, PhET simulations assist students in developing their problem solving and critical thinking skills (Verawati & Hikmawati, 2021; Yulianti et al., 2021). Results of studies explicitly demonstrate that PhET simulations can subsequently support students' learning of the wave-related concepts as well as quantum mechanics (Zollman et al., 2002; Baily & Finkelstein, 2009; Yulianti et al., 2021; Faletič & Kranjc, 2021).

For the aim of providing students, teachers, and educators with helpful resources around the world during the pandemic, since 2020, I was inspired to create some activities and worksheets for various topics of the PhET simulations: Introduction to Waves and Virtual Ripple Tank, Wave on a String, Wave Interference with Water and Sound, Spring and Resonance, Bending Light, Bending Light and Prisms, Convex Lens, Wave Interreference with Light and Slits, Quantum Wave Interference and Two Lasers, and Quantum Wave Interference and High Intensity. However, still there are only four guided activities (including two from myself) on the PhET website for such an important PhET simulation like *quantum wave interference* simulation which clearly visualizes an important demonstration in quantum mechanics called the double slit experiment (Thomas Young's experiment) and support an intuitive understanding of this experiment as well as the concept of wave-particle duality in quantum physics (Yulianti et al., 2021; Faletič & Kranjc, 2021; Baily & Finkelstein, 2009; McKagan et al., 2008; Zollman et al., 2002). This reveals the extent to which teachers embrace and focus on this topic in modern physics. Finally, I enthusiastically shared all of them with the PhET team to be utilized by other educators, teachers, and students on their websites too.

5.3. My Ultimate Thoughts

At the proposal phase of my thesis, I had planned to have a section called *Time.* However, after spending two years on my thesis, perceiving the importance of *time*, being in a critical time, and attempting to fit it into my thesis, I learned that it would not even fit into a long chapter. I wished to initiate my thesis with it though the thesis did not let me. Writing a thesis has its own well-defined structures, rules, and laws introduced and systematized a long *time* ago which must be followed and applied accordingly.

The *time* that I am talking about will be derived from my thoughts by hovering over classical and modern physics simultaneously. *Time* is continuous; it does not stop; it cannot be returned. This is a classical view about *time*. With this view, therefore, "our time is limited." Is it limited to one year, five years, 20 years, or 100 years? How many years? Science tells me five years. Are we sure about this *limited-ness*? However, nature of science with its tentativeness intervenes and brings us more views. This tentativeness creates unprecedented opportunities and possibilities that interweaves with technology. These two, nature of science and technology, together change the interpretation of *time* and let us go beyond the classical view and traditional rules and laws. We can return to the past to review, rethink, redesign, and recreate if we have already created anything. I try to create something and not only let myself but also others return to review, rethink, rework, and recreate on the past which belonged to me or anyone of us.

Do not ponder that you must understand all my words above (in this particular section) as I am not following the traditional rules and you have not been provided with enough data and information here, though not necessarily having a perception, data and information is required. You are free to perceive and look at them from any standpoint that it is comfortable for you. There is no homogenization here. However, just try not to hold a conventional view: be inclusive; consider duality; be creative. There are no citations and references here as these are my words and thoughts. The main point here is that *time* is instantaneously limited and unlimited for all of us. It only becomes unlimited with creating/creation and innovating/innovation even if it is very small and negligible. Nevertheless, the ignored parts can create differences, cause changes, and take us closer to *reality*. For this perspective, we need to change our ways of thinking and looking at the challenges and difficulties in the world since change is learning in itself. The beauty is in how we can look at the entangled issues differently and try to solve them. In the end, to completely comprehend the words written here, an understanding of the science of quantum physics would be beneficial.

5.4. Conclusion Towards Significant Outcomes

In this chapter, I illustrated how a crisis, with all its challenges and changes, can be converted to learning, relearning, reskilling and upskilling opportunities, constructive practices and progressive experiences for a teacher and educator who has been fluctuating and navigating in the zone of curriculum-as-lived-experience and curriculum-as-plan simultaneously (here and there both) since 2020. It is significant that 21st-century students need to be taught and assessed with updated and adapted approaches to the 21st-century scientists' science curricula and pedagogical tools (Milner-Bolotin, 2017a). I turned the lens toward myself and moved it over my own practices and experiences during a critical time. I demonstrated how teachers' distance learning and access to the on-time professional development and online cost-effective open-access resources can not only protect educational opportunities but also can provide students with a high-quality science education during the critical time of the COVID-19 pandemic.

This is what I learned in practice. It is relatively recent that everything has been brought to us by the tap of our fingers—with life-altering digital devices and technologies. However, the world has experienced an even higher-paced shift since 2020. I brought two revolutions to your attention: the Fourth Industrial Revolution (Schwab, 2016, 2017, 2018, Schwab & Davis, 2018; Schwab & Malleret, 2020) and the quantum revolution (Venegas-Gomez, 2020; Dowling & Milburn, 2003). From the perspective of experts and scholars, challenges and disruptions in the Fourth Industrial Revolution are being converted to new empowering opportunities for young pupils around the world. Simultaneously, they are being required to learn essential skills such as critical thinking (Bonney & Sternberg, 2016; Halpern, 2007; Grant, 1988; Lipman, 1995), problem solving (Bonney & Sternberg, 2016; Schwab & Davis, 2018; WEF, 2020a), creativity, innovation, collaboration, and so on to progress towards a more sustainable future in the 21st century. According to the results of studies reviewed here, these skills are mainly being practised and developed within STEM learning and STEM skills (Schwab, 2016; English, 2016; Beers, 2011; Hyde & Lindberg, 2007) which also help us understand the science behind our everyday use of fast-emerging technologies and digital devices—quantum physics embraced by big ideas in the contemporary sciences.

My learning and teaching practices and lived experiences in the field of physics and education, curriculum and pedagogy have granted me a revolutionary perspective which might provoke some teachers, educators, scholars, and experts in these fields. I argue that regular students in about the 7th grade, with any background knowledge, can initiate their physics learning. This learning can occur and be appreciated at an extracurricular and enrichment after-school science program (DeCoito, 2016; 2015b; Xu et al., 2015; NSF, 2020; Amgen Canada and Let's Talk Science, 2014, 2019; Science, Technology and Innovation Council, 2015; CCA, 2015). Likewise, I strongly believe and emphasize that youths—8th and 9th graders—are able to develop their learning of quantum mechanics with a focussed, well-designed, and aimed curriculum on waves principles and basics of quantum physics—wave-quantum-curriculum. I have designed and utilized this curriculum in an extracurricular and enrichment after-school science program in British Columbia. My observations from the science program acknowledge the discussions and arguments.

For the aim of teaching (for teachers and educators) and learning (for students, particularly adolescents) such a curriculum and the scientists' science related to our contemporary life, we (teachers, educators, curriculum developers, education leaders) have to employ a curriculum and pedagogy updated and adapted to the Fourth Industrial Revolution that can strongly support young students' science learning in quantum mechanics. As argued before, quantum physics is the focal point and the intersection of the physical, biological, and digital technologies and sciences of the 21st century. It is significant that for teaching and learning the most complicated and abstract concept in physics, not only students but also teachers, particularly science teachers without a physics background knowledge, require simplified and visualized educational instructional resources such as guided activities accompanied with simulations (McKagan et al., 2008; Zollman et al., 2002; Baily & Finkelstein, 2009; Yulianti et al., 2021; Faletič & Kranjc, 2021). Today, the effectiveness of the basic and classical simulations, visualized instructional resources, and simulation-based inquiry learning (de Jong, 2011; Mayer & Alexander, 2016; Day & Goldstone, 2009) in quantum mechanics is significant (McKagan et al., 2008; Zollman et al., 2002; Faletič & Kranjc, 2021; Baily & Finkelstein, 2009; Yulianti et al., 2021). These are strongly recommended in teaching the fundamentals of quantum physics, guiding, engaging, and encouraging adolescents towards contemporary knowledge for the aim of enabling them in their 21st-century life and their future careers as well.

To empower young students, particularly girls who are underrepresented in mathematical sciences (Natural Sciences and Engineering Research Council of Canada, 2010; American Physical Society, 2015; Hussénius, 2020; NSF, 2016, 2017; Robnett & John, 2020; Archer et al., 2017; DeCoito, 2016; AAUW, 2010, 2015; Ceci, 2014; Baram-Tsabari & Yarden, 2008; Kahn & Ginther, 2017), my perception of the outcomes of studies and practices is that they may benefit by initiating their learning in the physical and mathematical sciences at an early age when they hold a higher level of interest and participation in STEM (Bennett & Hogarth, 2009; Hsieh et al., 2019, DeCoito, 2016, 2015a; Amgen Canada and Let's Talk Science, 2014). Such initiation would create opportunities to broaden girls' participation and increase their self-confidence in science class, in school, in society, in life, and, finally, in their future career in which fields, like physics, still experience a gender gap (DeCoito, 2016, 2015a; Science, Technology and Innovation Council, 2015; CCA, 2015; NSF, 2020; Xu et al., 2015; Amgen Canada and Let's Talk Science, 2019; AAUW, 2010). According to Pinar's method of currere, with this approach, we would be able to reconstruct and create a *knowledge-based society* in which youths learn scientific knowledge and skills not as a school subject but also to succeed in their lives and future careers.

However, we still need more studies on adolescents' learning outcomes at an extracurricular and enrichment after-school science program, with a particular focus on the subject of physics, incorporating the big ideas of quantum mechanics. We need to study and examine the extent to which this idea has helped students' physics learning at an early age.

5.5. Implications for Further Research

In this chapter, I discuss succeeding research on this dissertation. This exploratory study gives rise to a great potential for further empirical study on young students participating in the Science Circles Program (SCP). I suggest that further studies can be approached as a case study by supporting required evidence such as data collection with observing classes and surveying participants in the science program. This approach will help us hear students' perspectives and voices and learn the extent to which this science program has been successful in engaging, supporting, and enhancing young students' interest and participation in this abandoned field of science, particularly by females.

Further, a researcher can develop various hypotheses and claims related to the posed questions. With all the facets of the present study, I believe that a case-study approach is well suited to investigate more and further the research since it may offer insights that might not be achieved through other approaches. According to the type of questions that will be answered in this further research and raised above, the case study is the best methodology that fulfills the required needs and concerns regarding the issue. This research can be conducted on a small group of adolescents since the object of the case study should focus on a person or group of people (Yin, 1994, 2014), thus making this approach a particularly appropriate one. Additionally, this method is useful for examining contemporary events and issues related to curriculum, pedagogy, and technology.

Contemporary educational conditions and issues in the case-study setting should be available for the participant-observation. The researcher, as an instructor or director, would not be a passive observer and outsider. “Participant-observation provides certain unusual opportunities for collecting case study data” (Yin, 2014, p. 116). As such, it is a great opportunity for the investigator to have access to students’ homework submissions for further investigation in their assignments and work at home where they complete their learning. Moreover, according to Yin (2014), “another distinctive opportunity is the ability to perceive reality from the viewpoint of someone ‘inside’ a case rather than external to it.” Thus, this can be an unprecedented opportunity to examine and explore the effect of a specialized teacher on the youths’ physics learning if the researcher is a science teacher with a physics background. The researcher can attempt to “produce a greater variety of situations for the purposes of collecting data” (p.117); in some sessions, there can be multiple observers. The evidence will be based on various approaches, for example, direct observation, the use of various pedagogical tools, curricular changes/curriculum transformation, diversion of theory to practice, connecting curriculum content to the youths’ everyday lives and lived experiences, and the core skills of the 21st-century.

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