

**Pedagogical Response of Manitoba Grade 9 and 10 Science Teachers During the
COVID-19 Pandemic: A Mixed Methods Case Study**

by

Kathleen A. Foerster

A Thesis submitted to the Faculty of Graduate and Postdoctoral Studies of
The University of Manitoba
in partial fulfillment of the degree of
DOCTOR OF PHILOSOPHY

Faculty of Education
University of Manitoba
Winnipeg

Copyright © 2026 Kathleen A. Foerster

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Abstract

When the COVID-19 global pandemic began in 2020, Manitoba teachers adapted their courses to modes of delivery which included remote teaching from home or school; blended learning; and other levels of restricted teaching. The pandemic impacted teaching and learning at all grade levels, however, impacts for Grade 9 and 10 science students are of particular significance as these students had limited opportunity to engage in the kinds of practical work needed to develop functional scientific literacy while enrolled in Manitoba's final mandated science courses.

During this time period and within the constraints of changing protocols, science teachers' choices regarding the curricular units and learning outcomes they prioritized and how they taught are likely to have impacted student development of scientific literacy. Data was collected over a four-month period in this two-phase mixed methods case study: in the first phase, through an anonymous online survey of Manitoba Grade 9 and Grade 10 science teachers with teaching experience in these courses prior to and during the pandemic ($N = 58$); and in the second phase through follow-up interviews of a sub-sample of teacher respondents ($n = 11$). The study followed a sequential explanatory design, with an integrated interpretation of the two forms of data and their results. Guided by the research questions, the findings from this study afford knowledge to prepare for future periods of disrupted science education and for other situations where practical learning might be restricted; support a vision for increased access to science education in remote communities; and offer insights into teachers' beliefs about what is most important for Grade 9 and Grade 10 science students that can inform professional learning initiatives and curriculum development. The collective contributions of Manitoba Grade 9 and 10 teachers united in teaching scientific concepts, skills and attitudes through constraints imposed by the COVID-19 pandemic confirm value for practical and collaborative opportunities to learn

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

science as reported in the key scholarship; and expose agency for instructional approaches to prepare a scientifically literate citizenry for the 21st century.

Keywords: COVID-19 pandemic, secondary science, scientific literacy, practical work, remote learning

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Acknowledgements

The University of Manitoba campuses are located on the original lands of Anishinaabeg, Ininiwak, Anisininewuk, Dakota Oyate, Dene and Inuit, and on the National Homeland of the Red River Métis. I respect the Treaties that were made on these territories, acknowledge the harms and mistakes of the past, and am dedicated to moving forward in partnership with Indigenous communities in a spirit of reconciliation and collaboration.

I would like to express my sincere appreciation, love and gratitude to my late parents for their unconditional support and values that drive my life and work, and for fostering a deep love for learning that inspired my lifelong educational journey. Thank you also to my many high school science students who provided endless motivation to contribute to science education in Manitoba; and to my children for sharing a passion for science that led them to their science-based careers. I am truly grateful for the love, support and encouragement of all the dear people in my life, who provided the fuel to help me reach the finish line.

I deeply appreciate and am grateful for the advice, expertise and ongoing support of my academic advisor, Dr. Lilian Pozzer, and for challenging me throughout this process. I would also like to thank my committee members Dr. Martha Koch and Dr. Bruno de Oliveira Jayme for all of your time, encouragement and valuable feedback. I also give sincere thanks to each of the participants for their generosity in sharing their experiences, and for their dedication to science education in Manitoba.

Finally, I wish to extend my gratitude for the financial assistance I received throughout my PhD program at the University of Manitoba which included the Delta Kappa Gamma Mary E. Lamont Fellowship, Arthur Stinner Memorial Fellowship in Science Education and the Faculty of Graduate Studies Research Completion Scholarship.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Table of Contents

Abstract -----	ii
Acknowledgements -----	iv
Table of Contents-----	v
Chapter I: Context of the Study -----	10
Research Questions -----	11
Phase I Sub-Questions-----	12
Phase II Sub-Questions-----	12
Purpose and Significance of the Study-----	12
Chapter II: Literature Review -----	15
Scientific Literacy-----	15
Developing Functional Scientific Literacy -----	18
Learning Theories in Science Education and the Development of Scientific Literacy	21
Experiential Learning-----	22
Active Learning -----	26
Scientific Literacy within the Manitoba Curriculum-----	30
Five Foundations for Scientific Literacy -----	31
General Learning Outcomes (GLOs)-----	33
Specific Learning Outcomes (SLOs)-----	33
Cluster 0 Overall Skills and Attitudes SLOs -----	36
Pedagogy in Remote and Restricted Science Education-----	39
Remote Teaching and Learning -----	43
Remote Pedagogy in Science Disciplines -----	45
Chapter III: Methodology and Methods-----	57
Philosophical Assumptions -----	57
Case Study Methodology -----	60
Mixed Methods Research Design-----	62
Methods-----	66
Ethical Considerations-----	68
Recruitment of Participants-----	69
Data Collection -----	72

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Data Analysis -----	74
Phase I Analysis -----	74
Phase II Analysis -----	76
Integrated Analysis-----	81
Research Quality and Rigour -----	83
Chapter IV: Findings and Discussion -----	87
Phase I: Survey Findings and Discussion-----	87
Demographic Survey Questions 1 - 7 -----	89
Survey Questions 1 - 4 -----	89
Survey Questions 5 – 6 -----	92
Survey Questions 7 - 8 -----	92
Survey Questions 9 - 10 -----	94
Survey Questions 11 - 12 -----	94
Survey Questions 13 – 14 -----	97
Survey Questions 15 – 16 -----	99
Survey Questions 17 – 18 -----	101
Survey Questions 19 – 20 -----	102
Survey Question 21 -----	104
Survey Question 22 -----	105
Survey Question 23 -----	107
Survey Question 24 -----	108
Survey Questions 25 – 26 -----	109
Survey Questions 27 – 28 -----	112
Survey Questions 29 – 30 -----	117
Summary of Phase I Findings -----	121
Phase II: Interview Findings and Discussion-----	122
Theme One -----	128
Theme Two -----	141
Theme Three -----	148
Theme Four -----	202
Theme Five-----	216

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Theme Six -----	246
Theme Seven-----	257
Summary of Phase II Findings -----	271
Integrated Analysis of Phase I and Phase II -----	274
Research Limitations -----	284
Chapter V: Conclusions -----	288
Contributions and Recommendations for Practice, Theory and Research -----	291
References -----	297
Appendix A Research Ethics Approval Letter -----	331
Appendix B Teacher Survey -----	332
Demographic Data -----	332
Research Questions -----	333
Appendix C Teacher Interview Protocol-----	345
Appendix D Abbreviations used in this Study -----	348
Appendix E Code Groups, Codes and Abbreviations used in Transcript Analysis-----	349

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

List of Tables

Table 1. Research Sub-questions for Phase I and Phase II Research Instruments -----	67
Table 2. Demographic Survey Questions 1 - 7 -----	87
Table 3. Survey Questions 1 - 4 Responses -----	89
Table 4. Survey Questions 5 - 6 Responses-----	92
Table 5. Survey Questions 7 - 8 Responses-----	93
Table 6. Survey Questions 9 - 10 Responses -----	94
Table 7. Survey Questions 11 - 12 Responses-----	94
Table 8. Survey Questions 13 - 14 Responses-----	97
Table 9. Survey Questions 15 - 16 Responses-----	99
Table 10. Survey Questions 17 - 18 Responses -----	98
Table 11. Survey Questions 19 - 20 Responses -----	102
Table 12. Survey Question 21 Responses-----	104
Table 13. Survey Question 22 Responses-----	106
Table 14. Survey Question 23 Responses-----	107
Table 15. Survey Question 24 Responses-----	108
Table 16. Survey Question 25 - 26 Responses -----	109
Table 17. Survey Questions 27 - 28 Responses -----	112
Table 18. Survey Questions 29 - 30 Responses -----	118
Table D1. Abbreviations used in this Study -----	348
Table E1. Code Groups, Codes and Abbreviations used in Transcript Analysis -----	349

List of Figures

Figure 1. Code Group Map -----	124
Figure 2. Categories and Sub-categories -----	126

Chapter I: Context of the Study

With the closure of Manitoba school buildings in response to the World Health Organization's announcement of the COVID-19 global pandemic on March 11, 2020, teachers were left to rapidly shift and adapt their courses to a remote delivery mode from their homes for the remainder of the school year. When school buildings opened in September 2020, a blended learning model where students attended classes every second day was adopted by most Manitoba high schools. This continued through May 2021, after which provincial safety guidelines mandated remote learning for the remainder of the school year. In-class learning for all students began in September 2021, however remote learning was again mandated in January 2022. When in-class learning resumed again in late January 2022, it remained through June 2023, when the emergency phase of the pandemic ended.

From my high school science teaching experience during the COVID-19 pandemic and from dialogue with other science teachers in Manitoba, it was my understanding that curricular and pedagogical choices were constrained as a result of the pandemic, at least in some school divisions. Throughout the periods of remote learning, blended learning, and return to daily in-class learning in 2022, ongoing pandemic safety protocols limited what science educators taught and how they taught their courses. Physical distancing reduced or eliminated opportunities for group investigations and experiments, group project design and testing with discussion, team debates, presentations and in-person conferencing. Other safety protocols including routine sanitizing of desks, chairs and laboratory equipment; quarantining requirements for paper copies; and student scheduling designed to minimize hallway congestion further crippled “hands-on” experiential learning opportunities by reducing actual in-class time.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

As the COVID-19 pandemic continued and teachers negotiated learning outcomes and activities amid pandemic protocols that restricted practical learning opportunities in science classrooms, the implications of teachers' pedagogical decisions for the development of student scientific literacy during this period was of special interest, inasmuch as practical learning activities that foster "essential aspects of science" including scientific and technological skills are vital for students to develop scientific literacy (Manitoba Education and Training [MET], 2000, p. 2.3). Moreover, the complex cognitive and metacognitive processes necessary to advance the development of scientific literacy demand practice (Natale et al., 2021). Given the importance of practical work to develop conceptual understanding, skills and attitudes in science, the opportunities for students to achieve functional scientific literacy may have been hindered during the COVID-19 pandemic. It was therefore important to find out what pedagogical choices Manitoba teachers made regarding how they teach science, and which learning outcomes they prioritized throughout this period. As such, this study was designed to investigate the pedagogical choices made by Manitoba Grade 9 and 10 science teachers during the COVID-19 pandemic - what they chose to teach and how they taught it, and to discuss the potential implications of these choices to the development of students' scientific literacy.

Research Questions

The main research question guiding this study was: "How do the curricular content and pedagogical approaches prioritized by Manitoba Grade 9 and 10 science teachers during the COVID-19 pandemic impact their potential to advance student scientific literacy?" There were two phases in this study, each with two sub-questions. Phase I was when the survey was administered while Phase II was when the teacher interviews were conducted. Each sub-question

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

focused on aspects of teachers' pedagogical decisions during the COVID-19 pandemic and was designed to help answer the main research question.

Phase I Sub-Questions

1. What curricular units and learning outcomes did Manitoba Grade 9 and Grade 10 science teachers prioritize, prior to and during the COVID-19 pandemic?
2. Which Grade 9 and Grade 10 science learning outcomes were taught through practical work prior to the pandemic and which ones were taught through alternative activities amid school lockdowns and restrictions during the pandemic?

Phase II Sub-Questions

1. In what ways did teachers limit and/or adjust practical learning opportunities for Grade 9 and Grade 10 science students during the pandemic?
2. How did teachers perceive alternatives to practical learning activities as a means of effectively promoting scientific literacy?

Purpose and Significance of the Study

As the development of scientific literacy requires practical work with specialized equipment and opportunities to practice the nature of science (Bencze et al., 2020), the decisions teachers made while teaching Grades 9 and 10 science under the strain of pandemic lockdowns and restrictions may have important implications for these students. As teachers rapidly and frequently adjusted their teaching to meet pandemic protocols, the units and learning outcomes they prioritized and their approaches to foster scientific literacy without practical, experiential components while developing and testing alternative learning opportunities are important for science educators to consider.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The COVID-19 pandemic impacted science teaching and learning at all levels, but as Grade 9 and Grade 10 science are the final mandated science courses in the province (Manitoba Education and Youth [MEY], 2003), teachers' pedagogical decisions in these grades are arguably of particular importance as students may choose to end their formal science education with these courses.

Data collected from Grade 9 and Grade 10 science teachers regarding pedagogical decisions during the pandemic offer insights into the impacts of these decisions on students' opportunities to learn scientific literacy content, skills and attitudes, as per definitions of scientific literacy in the literature. Because students' scientific literacy helps them to select, analyze and use information to back up their thoughts as they judge, position themselves, decide and/or act with relevant issues in their daily lives, it is extremely necessary for all citizens to become scientifically literate (Maia et al., 2021). Moreover, scientific literacy knowledge, skills and attitudes are critical for a sustainable future—for human health, environment and economy, and overall quality of life (MEY, 2003).

The findings of this study might also intertwine with the myriad of alternative ways of teaching and learning that made their way into classrooms throughout the pandemic. For instance, information about the alternative teaching approaches teachers created in response to restricted practical learning opportunities during the pandemic and their effectiveness in supporting student development of scientific literacy may be useful for teachers in similar emergencies. Moreover, the findings of this study may benefit science teachers in other settings where practical learning is simply not feasible, such as when students are unable to attend school, or school infrastructures do not support laboratories or specialized equipment. Likewise, the research findings may be of interest for the development of supports to increase access to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

science education in remote communities, or for adult education centers and adult learners in distant/remote communities pursuing high school equivalency.

Further, the findings might add to the K-12 online, remote, and blended learning [BL] literature that has captured research attention and may persist in circumstances beyond the pandemic (Kumi-Yeboah et al., 2018), but whose growth “out-paced the production of reliable and valid research” (Harrell & Wendt, 2019, p. 259). Additionally, since “much can be learned about science teaching and learning in relation to our response to COVID-19” (Verma et al., 2020, p. 487), examining the curricular units and learning outcomes teachers prioritized during restricted periods of learning offers insights into the learning outcomes teachers believe are most important for Grade 9 and Grade 10 science learners. These insights may also inform curriculum, practice and policy (Kim & Asbury, 2020). Information about what teachers *did* teach in Grade 9 and Grade 10 science during the pandemic, and by extension what they *did not* teach, may also be useful to inform teachers of the critical scientific concepts, skills and attitudes they might address in earlier grades.

Finally, this study allowed science teachers the opportunity to reflect on the pedagogical decisions they made throughout the pandemic and on the effectiveness of their teaching approaches, and to assess alternative learning opportunities to advance scientific literacy whether practical work was restricted or not. As such, the collective responses of Grade 9 and Grade 10 science teachers revealed insights into perceived successful or unsuccessful approaches to the development of scientific literacy, and inspired teacher agency and new pedagogy to foster it. Overall, multiple stakeholders, including science students, science teachers, curriculum writers and other researchers stand to benefit from this research.

Chapter II: Literature Review

Scientific literacy is central to this study and its relevance to science education and students' lives are described in this chapter, by examining: definitions of scientific literacy; development of functional scientific literacy; learning theories in science education and the development of scientific literacy including experiential and active learning; scientific literacy within the Manitoba curriculum, the five foundations for scientific literacy and learning outcomes; pedagogy in remote and restricted science education; and remote teaching and learning in science disciplines during the COVID-19 pandemic.

Scientific Literacy

Although the term “scientific literacy” has been in use for over half a century (Lederman et al., 2014, p. 285), views on scientific literacy have developed over time. Current perspectives in science education for achieving scientific literacy have been chosen to ground this research. Science education scholars contend that a main goal of science education is to promote scientific literacy by fostering the development of knowledge and critical thinking necessary to make informed and personal decisions on societal issues, and to solve 21st century problems such as those of the COVID-19 pandemic (Lederman et al., 2014; Maia et al., 2021; Natale et al., 2021) or, simply put, “to embody what students are learning in science in order to act and live in the world” (Price & McNeill, 2013, p. 503). It is well recognized that only a small number of students will actually become scientists, but everyone needs to understand some fundamental ideas in science and how science works in order to critically navigate science and technology in their lives, consider the claims made by scientists, governments and organizations, and engage with scientific issues reported in the media (Murray, 2014).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

There is no fixed meaning or definition of scientific literacy. The enduring concept in science education discourse is drawn from long term debates around meaningful learning, student engagement, context-driven and relevant student-centered activities, and curriculum design (Loughran, 2011). Furthermore, chasing the vision of scientific literacy for students “brings into question not only *what* is taught, but also *how* it is taught – and that is when academic debate really can impact the work of teachers... what does it mean for how they conduct their teaching?” (Loughran, 2011, p. 141). I agree with Feinstein (2011) who notes that fostering scientific literacy is fundamentally about making science relevant and practical, and “not something that the teacher does alone, but rather something that students learn to do” (p. 180). Others also maintain that putting students in the center of the learning process into local and authentic inquiry where they engage in science practice rather than just learning about science is key to developing scientific literacy (Crujeiras-Pérez & Jiménez-Aleixandre, 2017). Moreover, scientific comprehension and reasoning skills are known to improve through active learning approaches and experiential engagement (Beauchamp et al., 2021; Valladares, 2021). Contemporary science education literature reveals that to develop scientific literacy students must have opportunities to: investigate socio-scientific problems to extend learning beyond concepts, theories and scientific laws; understand how knowledge is constructed and legitimized within scientific logic; and apply scientific knowledge, attitudes and skills while conducting routine scientific practice as scientists do (Natale et al., 2021). Since scientists unite conceptual and procedural knowledge to confront authentic problems, Hodson (1993) argues that scientific literacy is best achieved when science education presents a similar approach and when students have opportunity to conduct research; to practice skills; to think critically and reflectively; and to make higher order decisions (Duran et al., 2016).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Drawing on this literature, in this study I adopt the perspective that scientific literacy is further developed when students acquire conceptual and procedural knowledge through authentic learning environments where they have opportunity to practice critical thinking and skills. I think of authentic environments and practices as those that allow students to utilize thought processes and develop procedural knowledge while they engage in investigations to demonstrate conceptual conclusions that are already known. Scientific literacy requires conceptual knowledge that goes beyond learning scientific concepts and includes procedural knowledge or essential skills to understand and participate in science and to achieve personal and societal goals (Croce & Firestone, 2020; Singh-Pillay & Naidoo, 2020; Valladares, 2021). Traditionally referred to as lab-based or field-based hands-on work, science educators often refer to such procedural knowledge acquired through performing as “practical work” (Hodson, 2014, p. 2538; Vanhorn et al., 2019). “Scientific practices extend well beyond cognitive operations to most vividly involve practical work, technical skills and material resources” (Allchin, 2014, p. 1925); indeed, greater understanding of science is achieved when technical and procedural skills are developed through hands-on laboratory experience (Ożadowicz, 2020). Studies comparing experiential learning to lecture based learning in STEM (Science, Technology, Engineering and Mathematics) courses confirm that hands-on learning positively correlates with enhanced academic achievement (Anderson et al., 2020; Cohen Zilka, 2021). Opere (2021) explicitly describes how an approach to teaching science that neglects to provide experimental learning experiences, does not integrate students’ ideas, or excludes skills that are critical to proper interpretation of scientific concepts might be flawed. In fact, the recent reimagining of scientific literacy emphasizes that practical work now constitutes an integral part of achieving it (Croce & Firestone, 2020).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Given the focus of my study, in the next sections I consider: how limitations to practical work may impact student development of functional scientific literacy; how scientific literacy is framed within the Manitoba science curriculum documents; how teaching science throughout fluctuating periods of remote, blended and restricted in-class learning levies pedagogical challenges for fostering scientific literacy; and important findings from empirical studies in science education related to teaching and learning throughout the COVID-19 pandemic.

Developing Functional Scientific Literacy

The notion of “functional” scientific literacy is captured by Croce and Firestone (2020). They envision scientific literacy as a social and international inquiry process that requires contextually positioning practical work within scientific inquiry (SI) including systematic and investigative approaches used to answer questions of interest. Within the nature of science (NOS)—where scientific knowledge is socially and culturally embedded—there is a need to cognitively engage students in meaningful long-term learning (Allchin, 2014). Allchin (2014) reports the importance of NOS in supporting functional scientific literacy has earned its place in curriculum standards internationally alongside laboratory skills and experimentation in SI instruction (Allchin, 2014; McBride et al., 2004). Multiple scholars support this perspective, and propose that in addition to practical skill building within NOS and SI instruction, using socio-scientific issues (SSI) such as vaccine development and distribution during a pandemic to frame authentic learning activities can provide deeper understandings and conceptualizations that contribute to the development of scientific literacy (e.g., Bencze et al., 2020; Maia et al., 2021; Moura, 2025), among others. Some scholars suggest functional scientific literacy should be the goal of science education, as all students must become “competent outsiders” equipped with knowledge and the best tools to evaluate the credibility of scientific information they encounter

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in today's world and media, even if the science is beyond their understanding (Osborne & Pimentel, 2022, p. 246).

Interest in the role of social interactions in the process of scientific literacy teaching and learning pervades recent science education literature (Croce & Firestone, 2020; Moura, 2025; Osborne & Pimentel, 2022). Frequently, this is presented in tandem with the necessity of multimodal learning opportunities that enable students to develop the knowledge, skills and attitudes to understand local, national and global scientific issues to develop functional scientific literacy. To become functionally literate, students must also learn how to interpret and communicate science through text, graphs, diagrams, photographs, dialogue and their actions while synthesizing and defending ideas; and to accommodate new information as they reframe concepts and critically engage with science (Croce & Firestone, 2020; Maia et al., 2021). Furthermore, the scientific literacy "for all" advocated in science education research and international policy initiatives is geared toward advancing student capabilities to creatively transfer knowledge, skills and values to new situations and across disciplines (Erduran et al., 2012). Valladares (2021) contends this is necessary to empower students with personal and collective agency to cope with the challenges of the 21st century; which Moura (2025) suggests is compulsory to build a citizenship inspired to face unexpected challenges as innovative, adaptable and resilient problem solvers.

As the standard of scientific literacy and pedagogy to achieve it have evolved, some prominent interdisciplinary frameworks have emerged in addition to SI and NOS, such as project-based learning (PBL) and place-based education (PBE). While PBL scholars describe the potential of this approach to enhance functional scientific literacy as students investigate, collaborate and deliberate interesting, relevant questions that connect curricular knowledge with

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

procedural knowledge and skills (Croce & Firestone, 2020; Juuti et al., 2021), PBE scholars propose that scientific literacy is enhanced even further when these authentic questions emerge in students' local "places" or home communities (Kim et al., 2019). They maintain that meaningful context fosters engagement through cognitive, affective and social aspects to promote functional scientific literacy (Tal, 2013). Collectively, such frameworks offer students an incomparable opportunity to "do science" with questions grounded in what they know and care about, while motivating their interest and engagement in the interplay of theory, design and evidence beyond what standard laboratory exercises might provide (Hodson, 2014).

Functional scientific literacy is continuously developed, in small steps, through the interconnection of critical thinking, self-awareness-raising, critical positioning, and decision-making (Allchin, 2014; Almeida et al., 2022). Almeida et al.'s embedded inclusion of "self-awareness-raising" as a quality of functional scientific literacy adds metacognition to the science education repertoire of important elements required for its achievement. Recent evidence from Mutambuki et al. (2020) shows that when chemistry students are engaged in metacognitive activities to think about their learning, they display improved conceptual understanding and complex problem-solving abilities, along with increased self-efficacy, motivation, persistence and retention in chemistry. Students benefit from opportunities to make the necessary connections described above, and to think and act critically, which is afforded when science learning is situated within current and relevant issues, such as the anthropogenic influences on climate change, for example (Allchin, 2014). If students are equipped with knowledge of science, NOS and SI; have opportunity to practice conceptual and procedural understandings within the context of SSIs, PBL or PBE; and make informed decisions about meaningful issues, they can develop critical or functional scientific literacy (Calabrese Barton & Tan, 2014;

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Lederman et al., 2014; Mueller & Zeidler, 2010)—“the sine qua non of what it means to be scientifically literate” (Allchin, 2014, p. 1914).

Learning Theories in Science Education and the Development of Scientific Literacy

This study is grounded on current approaches to scientific literacy and the notion that, for students to become scientifically literate, they require opportunities to practice science to learn essential scientific and technological concepts, skills and attitudes. That is, to be a scientifically literate citizen, one requires conceptual, procedural and investigative knowledge and skills; students do not learn science and do not become scientifically literate by only doing science. Thus, although compelling, Hodson's (1993) view that “Science brings about three kinds of learning”: enhanced conceptual understanding; enhanced procedural knowledge; and enhanced investigative expertise (pp. 125-126), science educators must also remember that “one cannot learn enough about science by restricting activities to doing science...[as] scientific practice is a complex, socially constructed activity” (p. 126); nor can one learn to do science through a prescribed set of processes to be applied in all situations (Hodson, 2014).

Learning theories accompanying the necessity of practical work to develop scientific literacy include experiential learning theory and active learning theory, which draw on the work of many scholars who gave experience a central role in their theories of human learning, such as: William James, Mary Parker Follett, John Dewey, Kurt Lewin, Jean Piaget, Lev Vygotsky, Carl Jung, Paulo Freire and Carl Rogers (Kolb & Kolb, 2012; Petersen & Kolb, 2018). Experiential learning and active learning are both relevant to this study, so I have provided an explanation of each while emphasizing distinguishing features.

Experiential Learning

A spectrum of meanings, practices and ideologies associated with experiential learning have unfolded since its 1946 origin (Moon, 2004; Seaman et al., 2017), when it was reified as a naturally occurring, psychological process and converted from a practice to a theory. A general definition was established: “An independent learner, cognitively reflecting on concrete experience to construct new understandings, perhaps with the assistance of an educator, toward some social goal of progress or improvement” (Fenwick, 2001, p. 7). Elements of experiential learning theory align with Vygotsky’s sociocultural learning theory, where the teacher organizes interactive educational activities in which social knowledge is created (Daniels, 1993). While each of these distinct theories emphasize that learning requires meaningful participation in experiences and learners do not acquire information passively, experiential learning can occur outside of a social or cultural context.

According to Petersen and Kolb (2018), “it is not experience, but experiencing that is the source of learning” (p. 228) and the change in an individual that results from their reflection on a direct experience (Itin, 1999; Seaman et al., 2017). This reflection draws upon prior knowledge (Kuk and Holst, 2018), as we might for example reflect upon experiencing childhood injuries that taught us valuable lessons and saved us from further injury. Petersen and Kolb (2018) emphasize that learning results when meaning is found from deep involvement in experience, and “without new experiences there can be no real learning; people only recombine and reiterate what they already know” (p. 228). Dale (1970) posits concrete, direct, firsthand experiences are the foundation of learning, and “the bedrock of all education” (p. 98). Moreover, argues Dale, remembering and abstracting direct, purposeful experiences enhances conceptual understanding. As science educators introduce new technical and procedural skill-building experiences and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

student thinking extends beyond cognitive operations and scientific concepts, greater understanding of science is achieved and scientific literacy is advanced (Allchin, 2014; Britt et al., 2014; Croce & Firestone, 2020; Singh-Pillay & Naidoo, 2020).

While students develop functional scientific literacy through diverse learning experiences, it is important to recognize not every experience results in learning, but rather the relationship between experience, reflection based on prior knowledge, and resulting learned experience, which constitutes experiential learning (Kuk and Holst, 2018). Moon (2004) echoes the difference between having an experience and learning from experience, while expressing concern with the assumption that learning can result from any experience and emphasizing that experiential learning takes place without the direct mediation of a teaching process. Other scholars indicate action, reflection, abstraction and application are necessary for experiential learning: "The change in an individual results from reflection on a direct experience that results in new abstractions and applications" (Seaman et al., 2017, p. 18). In agreement with this literature, with Manitoba curriculum documents identifying Grade 9 and Grade 10 learners as increasingly capable of abstract thinking (MET, 2000; MEY, 2003), I believe that experiential learning is of critical importance for Grade 9 and Grade 10 students in preparing a scientifically literate citizenry capable of applying new abstractions to 21st century problems demanding scientific expertise and solutions.

New experiences to foster learning scientific literacy concepts, skills and attitudes require a certain amount of practical work. Eighty-five years ago, Dewey proposed that in order to learn, our "habitual experience must be interrupted by deep experiencing, such as when we are stuck with a problem or difficulty or struck by the strangeness of something unusual outside of our usual experience" (Petersen & Kolb, 2018, p. 228). Manitoba Education reflects this idea in

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

their statement, "Experiences of intense involvement are optimal opportunities for teaching engagement in learning" and students should have regular exposure (MET, 2000, p. 21). Since "understanding by its very nature, is related to action" (Layton, 1991, p. 43), further investigation between theory and action is needed.

Of great significance to this research, is Layton's (1991) perspective that technical skill must be learned experientially; technological judgements cannot be based on theoretical knowledge alone. Layton argues that students can only deconstruct and reconstruct scientific knowledge when they have opportunities for practical action. Yang et al. (2021) defend this "theory of learning-by-doing" as they confirm students deepen and broaden their understanding of problems with hands-on practice, as they connect their understanding in their minds by "doing" (p. 384). Practical action is essential for students to learn science, and many pedagogical approaches suggest the need for practical elements in science learning. For instance, some theorists maintain that cognitive strategies associated with practical work in science education include discrepant events or cognitive dissonance, which stems from Piaget's idea that learners require a "jolt out of their ordinary way of looking" when they perform some relevant action (Agarkar, 2019, p. 852). Agarkar (2019) describes other significant theoretical influences in science education grounded in Vygotsky's view of constructivism where learners engage in a problem to construct new knowledge, often through practical experiences in a sociocultural context. For instance, science students might engage in constructivist learning through project-based learning (PBL), which requires students to engage in real-world activities to assimilate knowledge through investigation, explanation and discussion; or through inquiry-based learning in which students question, predict, observe, infer, measure, classify, experiment, collect, analyze and interpret data while developing fundamental attitudes of curiosity, skepticism, and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

creativity that are foundational to scientific literacy (MET, 2000; MEY, 2003). Constructivist approaches for teaching science often include grounded learning cycles such as the three stage SCIS (Science Curriculum Improvement Study) cycle, which contributed to the development of one of the most widely used learning models, the BSCS (Biological Sciences Curriculum Study) 5E learning cycle (Withers & Schinske, 2016). Numerous studies report that learning gains are acquired when science teachers utilize all five stages of the 5E learning cycle: engagement, exploration, explanation, elaboration and evaluation (Suardana et al., 2018). These scholars describe how a more recent bookending expansion of 5E, the 7E learning cycle, augments with elicitation of students' own knowledge and with extension, where students relate and apply their learning to everyday life—each seen as essential for developing functional scientific literacy.

Other scholars present learning cycles that align with 7E and are relevant in experiential science education including Petersen and Kolb (2018) who highlight “experiencing” as both a mode of learning among four modes of the learning cycle (originally proposed by Kolb, 1984), and as a style of learning among nine styles. The four modes in Peterson and Kolb's experiential learning cycle are: experiencing, reflecting, thinking and acting, which are holistic and involve affective, perceptual, cognitive and behavioral aspects of an individual. A concrete experience demands reflective observation to find meaning that will engage abstract thinking, and lead to a decision to act. Nine learning styles described to support this action and accompany the four modes are: experiencing, imagining, reflecting, analyzing, thinking, deciding, acting, initiating, and balancing (Petersen & Kolb, 2018). Qualities of these nine styles of learning that are of importance to developing scientific literacy include: creating meaning through observation and reflection; integrating and systematizing ideas; disciplined involvement in abstract reasoning and logic; goal directed action integrating people and tasks; and flexible and adaptive decision

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

making. When analyzing interview data in this study, I considered these four modes and nine styles to seek understanding of teachers' decisions for promoting scientific literacy. Petersen and Kolb (2018) also tell us one's individual preference of learning style ultimately promotes learning habits or patterns which draw on some parts of the learning cycle over others, and influences how we view current situations, or perceive and decide future choices. Moreover, reflecting on learning style, habits or patterns is a powerful form of self awareness which is a critical component of metacognition and central to active learning theory.

Active Learning

Robertson (2018) defines active learning as “any type of instructional method which engages students in their learning process and requires meaningful learning activities, requiring students to think about what they are doing (metacognition)” (p. 20). Although these learning activities are not limited to being kinesthetic in nature, in order for students to develop functional scientific literacy, they require this active engagement in their learning process. Vanhorn et al. (2019) describe the progression of active learning theory through the visions expressed by several scholars, indicating this mode of learning “involves students doing things and thinking about the things they are doing” (p. 19). Prince's (2004) view that students need to embrace their role and thoughtfully engage in thinking about what they are learning is illuminated in Chickering and Gamson's (1987) definition of active learning:

Learning is not a spectator sport. Students do not learn much just by sitting in classes listening to teachers, memorizing prepackaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, and apply it to their daily lives. They must make what they learn part of themselves. (p. 5)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

This definition exposes why active learning is paramount to building functional scientific literacy alongside experiential learning through practical work. Students' metacognitive awareness and ability to self-regulate learning allows them to build capacity to reflect critically on their scientific knowledge in a variety of relevant settings (Prince, 2004), propping their functional ability to apply science. In keeping with this view, in Manitoba's curriculum standards documents, several Grades 9 and 10 "Cluster 0" Overall Skills and Attitudes include specific learning outcomes (SLOs) that highlight the necessity of higher order thinking skills and metacognition. For instance, "Demonstrate confidence in their ability to carry out investigations in science and to address STSE issues; Evaluate the original plan for an experiment and suggest improvements; Reflect on prior knowledge and experiences to develop new understandings; Assume the responsibilities of various roles within a group and evaluate which roles are most appropriate for given tasks" (MET, 2000, pp. 0.3-0.7; MEY, 2003, pp. 0.3-0.7).

Active learning demands a student's awareness of their own learning or metacognition as defined by Flavell (1979) as a means of cognitive monitoring. Thus, "effective teaching needs to engage students in thinking deeply about a topic at an appropriate level [while] monitoring their understanding" (Robertson, 2018, p. 27). Guidance is requisite for students to become active learners as they initiate knowledge construction and develop ownership of their learning (Prince, 2004). In fact, metacognition is identified as a dynamic learning process integral to all five foundations in Manitoba's senior science curriculum standards (MET, 2000). Important elements of metacognition include metacognitive knowledge, or one's beliefs about their learning capacity; metacognitive experiences, or conscious recognition of one's understandings or misunderstandings; and learning goals, the actions or strategies that help one learn (Robertson, 2018). Davies (2020) reminds us that, "The student knows more than the teacher about what and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

how he has learned” (p. 73). Robertson proposes that skill development accompanying student self-assessment is metacognitively significant for experiential learners; and that metacognition can indeed be taught, for instance through methods to help students activate their prior learning.

Koohang et al. (2016) contend it is the instructor's responsibility to design learning materials to successfully guide students to become “active learners” (p. 239). These scholars propose three stages to achieve active learning for knowledge construction: underpinning, ownership and engagement. Koohang et al. explain that ownership is how learners are empowered to take control of learning, and this requires learners to: set self-driven goals, self-mediate, self-reflect and be aware of learning, and self-assess. These scholars emphasize an experiential and collaborative environment, pointing out the instructors and students have essential roles and responsibilities for student success in active learning. Regan (2012) supports this view adding “little attention is given to what the student is obliged to do” (p. 21); and that the role of instructors is to facilitate optimal learning, but in turn, students have a role to participate fully to the best of their ability in all aspects of their learning. Students need opportunities however, to “verbalize their thinking and make it visible” (Robertson, 2018, p. 9), and “to learn how to learn” (p. 48).

Ideally, science students are afforded such opportunities in the setting of their classrooms and laboratories where they can do practical work, and learn from and with their teacher and peers, consequently increasing their opportunity to advance their scientific literacy. Emphasizing the connection between experiential and active learning, I agree with Robertson's (2018) claim that student-centered experiential learning settings promote metacognition through higher level thinking at the upper levels of Bloom's taxonomy. Extending thinking beyond remembering, understanding and applying, students can reach higher to include analyzing, evaluating and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

creating (McGuire & McGuire, 2018)—critical attributes of functional scientific literacy.

Furthermore, McGuire and McGuire propose knowledge of Bloom's taxonomy is helpful for students to assess and adjust their learning goals, and therefore useful to them as they learn how to learn, and "make what they learn part of themselves", as Chickering and Gamson (1987) proposed. In effect, as higher order thinking is required in active learning and advanced through experiential learning opportunities, I view both forms of learning as aligned with science education instructional models inclusive of 5E and 7E, essential for developing scientific literacy.

Empirical support for active learning is extensive (Prince, 2004), and closely linked with experiential learning in STEM fields. Studies in practical STEM classrooms have revealed measurable student gains when active learning is introduced. The integration of active learning into university biology courses in the US required students for instance to complete self-evaluations following a practical learning activity, and to find logic in their misconceptions through discussion (Walker et al., 2008). When students engage in active learning they have increased opportunity to address misconceptions, an important element of effective teaching (Prince, 2004). Important findings from Walker et al.'s study show that student benefits from active learning are most evident for students with lower grades, and that some students might resist active learning and require time and support to adopt it. Anderson et al. (2020) maintain scientific literacy is indeed enhanced when active learning is considered in partnership with experiential learning; and in recent decades has contributed to improved learning outcomes with even greater results when authentic and personal connections are made through common approaches in science, such as PBE (place-based education) and PBL (project-based learning). PBE and PBL are grounded on experiential and active learning theories, with great potential to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

foster student development of functional scientific literacy. Kim et al. (2019) described an empirical study revealing scientific literacy gains with seventh grade students in Korea through a community PBE approach; while Robertson (2018) noted that PBL challenges students to think deeply about their knowledge and then apply it as they develop complex learning skills.

Empirical studies suggest that as science education should promote experiential learning through a student-centered learning atmosphere, while allowing students to engage in project-based tasks (Hong et al., 2018), it supports PBL environments. Seaman et al. (2017) explains developments that took place in experiential learning theory were attractive to early project-based school curricula and have since progressed, which is evident in current models of PBL addressing scientific literacy by promoting scientific thinking through authentic learning tasks that also support metacognition (Croce & Firestone, 2020; Barrows & Tamblin, 1980; Savin-Baden, 2007). When students advance from novice to expert problem-solvers through active learning in PBL they become increasingly equipped to self-regulate, self-direct, and self-pace learning, promoting independence and positive attitudes about learning (Prince, 2004). Moreover, advises Prince, self-directed learning and metacognition that foster a deeper approach to learning are common to PBL, and lifelong learning.

Thus, experiential and active learning theories are central to critical thinking and to student development of functional scientific literacy and they fundamentally underscore learning outcomes and activities in the Manitoba Grade 9 and Grade 10 science curriculum documents (MET, 2000; MEY, 2003).

Scientific Literacy within the Manitoba Curriculum

The Manitoba science curriculum documents describe scientific literacy as “an essential and evolving combination of the science related knowledge, skills and attitudes students need to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

develop inquiry, problem-solving, and decision-making abilities" (MET, 2000, p. 1.2) necessary to make informed, critical decisions as "global interdependence; rapid scientific and technological innovation; the need for a sustainable environment, economy and society; and the pervasiveness of science and technology in daily life reinforce the importance of scientific literacy" (p. 1.2). This vision for scientific literacy within the Manitoba senior years science documents emerged in 1997, with the national document *Common Framework of Science Learning Outcomes: Pan-Canadian Protocol for Collaboration on School Curriculum* (MET, 2000). Despite lacking an effective operational definition at first, and some uncertainty regarding how the concept of scientific literacy would be realized through curriculum, instruction and learning in the province (Murray, 2014), the ten Manitoba Senior Years Science course curriculum standards documents were inspired by the Pan-Canadian Science Framework guidelines with the aim "to develop functional scientific literacy in all Canadian students" (MET, 2021). MET (2000) suggests that such opportunity is afforded to students when they study science through concrete and contextual learning processes that include scientific inquiry, technological problem solving (the design process), and decision making—a perspective echoed in the science education scholarship.

Five Foundations for Scientific Literacy. Manitoba Education's five "Foundations for Scientific Literacy" described in the science curriculum documents serve as the conceptual organizer and provide specific foundations for science education and scientific literacy in the province: A. Nature of Science and Technology (NOS); B. Science, Technology, Society and the Environment (STSE) (with Manitoba Sustainable Development Strategy incorporated); C. Scientific and Technological Skills and Attitudes; D. Essential Science Knowledge; and E. Unifying Concepts (MET, 2000). These five foundations for developing scientifically literate

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

students direct that science learning experiences “must incorporate the essential aspects of science and related applications” (p. 2.4). In my view, this includes conceptual knowledge, along with practical skills and scientific attitudes. While conceptual knowledge spans all five foundations, an emphasis on the necessity of practical skills and scientific attitudes for developing scientific literacy is pronounced in foundations B and C, which underscore “the design process” from Kindergarten to Grade 8, and technological problem solving in senior years’ courses (MEY, 2003). Proposing, creating and testing of prototypes, products and techniques in such problem solving requires practical work, and the skills and attitudes involved in these processes play an important role in the development of scientific understandings, and for the application of science and technology to new situations. Furthermore, prioritizing practical work aligns with the National Science Education Standards vision of change in science instruction, directing less emphasis on knowing scientific facts while increasing emphasis on integrated, active, investigative contextual learning (MET, 2000). Additional emphasis on practical work is seen in foundation C, as procedural skills fundamental to scientific inquiry: designing experiments, measuring and collecting data, are paired with fundamental scientific and technological attitudes for conducting scientific inquiry. MEY (2003) informs that lifelong development of positive attitudes helps to support students’ intellectual development and prepares them to responsibly apply science knowledge and procedural skills. Scientific and technological attitudes listed in foundation C include curiosity, skepticism, creativity, accuracy, precision, honesty and persistence, and are advanced through scientific practice.

The instructional philosophy in the Manitoba science curricula states the learning environment should employ a variety of instructional strategies inclusive of laboratory observations, field work, and the caring use of living organisms taught in a manner for students

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

to apply to their everyday lives, while also helping students develop an awareness for careers and vocations in the wide diversity of sciences (MEY, 2003). Further, the curriculum standards indicate that many scientific literacy tasks involve a complex interaction of skills, that with practice become “automatic” when the student loses awareness of skills executed (p. 37), as these are largely unconscious mental processes. To achieve this, science learners require regular practice to learn skills and to develop a repertoire of strategies to make meaning for application to science tasks— “knowing what to do, how to do it, when to do it, and why it is useful” (p. 37).

General Learning Outcomes (GLOs). Within each of the five foundations for scientific literacy, A through E, Manitoba’s curriculum standards describe 28 general learning outcomes (GLOs) expected of science students across all grade levels. These GLOs provide the depth and breadth for learning scientific literacy, and are few in number in each foundation. In foundation C: Scientific and Technological Skills and Attitudes, for example, GLOs include: “Students will recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations”; “students will demonstrate appropriate scientific-inquiry skills when seeking answers to questions”; and “students will demonstrate appropriate problem-solving skills when seeking solutions to technological challenges” (MEY, 2003, p. 12). Each of these learning outcomes requires students to do practical work to develop important skills along with scientific and technological attitudes to accompany their conceptual science knowledge. For instance, knowledge of Workplace Hazardous Materials Information System (WHMIS) and household safety symbols on cooking and cleaning products, pharmaceuticals and other domestic chemicals require student practical or hands-on opportunity to identify symbols on common items; along with practice of safe procedures for their storage, use and disposal. Another GLO in foundation C reads: “students

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

will demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind” (MEY, 2003, pp. 12-13). The pairing of scientific and technological skills and attitudes in foundation C might suggest their complementary roles for the development of student scientific literacy. From my experience as a teacher, I have observed how practical science learning activities allow students opportunity to develop scientific literacy as they apply their conceptual understanding, practice skills, and also develop important scientific attitudes like creatively determining how to accurately measure an irregularly shaped solid, for example; or to practice persistence while attempting to transfer a small volume of solution by pipette, with accuracy and precision. I have also observed students develop positive scientific attitudes through practical work, which in turn inspire and motivate further inquiry. Predicting the outcome of an experiment might invite curiosity for example, and curiosity has the potential to motivate further practical learning. As the Manitoba Science Curriculum Conceptual Organizer (MET, 2000, p. 15) presents a cyclical interactive view of the Manitoba Foundations for scientific literacy, I see skills and attitudes in foundation C as integrally foundational.

Grade 9 and Grade 10 science teachers are directed to observe students in action to assess procedural knowledge (MET, 2000, p. 42)—action is required to acquire procedural skills and accompanying scientific attitudes. The Manitoba Education science curriculum standards guide science teachers and are clear—practical work is seen as a necessary, or a preferred way to achieve these GLOs and to advance student scientific literacy.

Specific Learning Outcomes (SLOs). Specific or prescribed learning outcomes (SLOs), which support and promote the vision for scientific literacy, detail the knowledge, skills and attitudes students are expected to learn within each of the 4 units or thematic “clusters” for each

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

grade level or course (MET, 2000, MEY, 2003). The Grade 9 and Grade 10 science clusters include the requirement for teachers to provide students with knowledge, skills and attitudes in biology, chemistry and physics to foster general scientific literacy, while also preparing students for optional Grade 11 and Grade 12 courses in these disciplines. In total, there are 67 SLOs in the Grade 9 science clusters: Reproduction, Atoms and Elements, Nature of Electricity and Exploring the Universe; and 43 SLOs in the Grade 10 science clusters: Dynamics of Ecosystems, Chemistry in Action, In Motion and Weather Dynamics. These SLOs occupy a large portion of the curriculum documents, are linked to the specific GLOs they serve, and include suggestions for instruction: entry level knowledge, notes, learning resources, and student learning activities; along with suggestions for assessment (MET, 2000; MEY, 2003). Some SLOs suggest practical learning is part of the curriculum standards, requiring that students “investigate”, such as “investigate properties of substances”; “observe” and “collect” as in “observe, collect and analyze class data of single trait inheritance”; “construct” as in “construct electric circuits using schematic diagrams”; “experiment” as in “experiment to determine indicators of chemical change,” or “use” as in “use appropriate instruments and units to measure voltage (electrical potential difference), current and resistance” (examples from the Grade 9 course; MET, 2000, pp. 1.1-4.33). In Grade 10 science, the same SLO phrasing is used: “Investigate the law of conservation of mass, and recognize that mass is conserved in chemical reactions”; “investigate and classify reactions as synthesis, decomposition, single displacement, double displacement, or combustion”; “experiment to classify acids and bases using their characteristic properties”; “experiment to illustrate the effects of inertia in car crashes”; “observe and document a range of organisms that illustrate the biodiversity within a local or regional ecosystem” and “collect displacement data to calculate and graph velocity versus time for an object that is accelerating at

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

a constant rate” (MEY, 2003, pp. 1.1-4.36). It is difficult to conceive of ways that students might achieve these learning outcomes that require investigating, observing, constructing, experimenting, using and collecting, without doing practical work. From my experience and a close examination of the curricular SLOs in Grade 9 and Grade 10 science, the necessity of practical work is evident within each science discipline and cluster, and it aligns with the previously discussed literature emphasizing the value of practical work in science. In addition to the SLOs in each cluster in Grade 9 and 10 science, additional curricular SLOs linked with all four clusters in each course, are described in Cluster 0.

Cluster 0: Overall Skills and Attitudes SLOs. The SLOs in the Cluster 0 (pronounced Cluster Zero) “Overall Skills and Attitudes” broaden the importance of scientific skills and attitudes for learning science. They emphasize essential aspects of the processes and nature of science that are required to learn science and are presented in association with the related GLOs (MET, 2000; MEY, 2003). Each of the nine groups of Cluster 0 SLOs include several SLOs. Collectively, these include 48 skills and attitudes pertinent to both Grade 9 and Grade 10 science. Many of these SLOs require practical work to achieve. Examples of skill-based SLOs that require practical work include: “plan an experiment to answer a specific scientific question, and work cooperatively with group members to carry out a plan and troubleshoot problems as they arise”; “carry out procedures that comprise a fair test”; and “demonstrate work habits that ensure personal safety, the safety of others, as well as consideration for the environment” (MET, 2000, pp. 3.10-3.14). Examples of attitude-based SLOs that might be best achieved through authentic practice include: “Demonstrate confidence in the ability to carry out investigations in science and to address STSE issues”; “be sensitive and responsible in maintaining a balance between the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

needs of humans and a sustainable environment”; and “demonstrate personal involvement and be proactive with respect to STSE issues” (pp. 3.10-3.14).

I see Cluster 0 SLOs as indispensable in effectively guiding students through their scientific literacy journey in Grade 9 and Grade 10 science. Based on my analysis, Manitoba's framework and underlying principles provide a thorough base for understanding and promoting scientific literacy and convey a powerful message to science educators like myself, that essential skills and scientific attitudes that accompany conceptual understanding are critical to learning science and necessary for developing a scientifically literate citizenry. I also argue that the five foundations for scientific literacy and associated GLOs, along with the SLOs, including the Cluster 0 skills and attitudes SLOs, may only be fully attainable when students do practical work. Opportunities for developing and practicing scientific literacy skills and attitudes are indeed poised in GLOs within foundations B; C—with technological problem solving and inquiry-based decision-making embedded; and in Cluster 0 skills and attitudes outcomes. However, in order for science teachers to effectively address each learning outcome they need to make deliberate, informed decisions about which learning activities to select for their students and the best tools to use for each activity (MEY, 2003). The Manitoba science curriculum documents also state that in order to promote scientific literacy it is vital that teachers recognize how science best be taught; and for instructional environments to be effective, students require opportunities to work cooperatively with other students, to initiate investigations, to communicate their findings, and to complete projects that demonstrate their learning (MET, 2001, p. 1.3). Indeed, the development of student scientific literacy requires science teachers to interpret their curriculum and, ideally, provide students with effective practical learning opportunities—a perspective shared in the science education literature.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Further accentuating the significance of practical work in Grade 9 and 10 science, MEY (2003) advises that students in these grades learn best when their physical energy can be put toward experiential learning, and that effectively promoting scientific literacy requires that teachers engage their students in frequent kinesthetic activities. As an educator with significant experience teaching Grade 9 and 10 science, I recognize the tremendous value of practical work for students to learn scientific competencies in high school, and have observed scientific literacy advance in greater strides with an approach that incorporates daily practical work in Grade 9 and 10. Other opportunities for teachers to enrich scientific literacy competencies are found in science opportunities such as clubs, competitions and extracurricular activities offered in high schools, and in creative pedagogy that can extend beyond the school's walls. In my attempts to fulfil curriculum outcomes and maximize science learning opportunities for my students over many years, I was able to encourage many students to participate in independent research to advance their scientific literacy; and through local, national and international collaboration and competitions, many realized exciting lives and careers in STEM-related fields. Without GLOs and skills and attitude-related learning outcomes in Cluster 0 underpinning my pedagogy, and a personal interest and adequate resources to provide frequent practical work for my students, my students may not have had these opportunities.

In summary, the Manitoba Education science standards documents make clear that developing scientific literacy requires conceptual and procedural knowledge, skills and attitudes; and that the complex cognitive and metacognitive processes to advance the development of scientific literacy demand practice—but how to provide students with scientific practice throughout the pandemic's lockdowns and restrictions, however, remained a challenging question for teachers and researchers (Natale et al., 2021) throughout the pandemic emergency.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Pedagogy in Remote and Restricted Science Education

When the COVID-19 pandemic began, teachers around the globe reported that “decisions were required about what material to cover and what could not be covered” (International Council for Education and Teaching [ICET], 2020). As teachers made these decisions and adjusted their approaches, scholars advised this process would require time and practice (Chan et al., 2020; Chen et al., 2020). During the pandemic, Manitoba science teachers had to adjust their pedagogy through several periods of school closures requiring remote teaching and learning, blended teaching, and through other restrictions including physical distancing of students. However, teachers did not have training to develop the skills and expertise required to effectively teach science in these circumstances. This was something my colleagues and I quickly realized when we suddenly began teaching from home at the start of the pandemic. Donovan (2020) proposed that “while the online experience is something we will survive together; the day will come when we are back to some sort of ‘normal’ and can work with our students in person in class as usual” (p. 2920). That day could not arrive quickly enough for teachers like myself who value practical work and its importance for scientific literacy.

As teachers moved abruptly from in-class teaching without restrictions in March 2020 to teaching remotely, blended teaching, and teaching in-class with various restrictions, they had little time to prepare, design, learn and practice to instruct effectively. School closures are not new to education (Kim & Asbury, 2020), but with little time to prepare, teachers rapidly sought skills and adapted to remote teaching while their students adapted to remote learning simultaneously (Aguirre & Selampinar, 2020; Giordano & Christopher, 2020; Reicher, 2020). Although teachers have pedagogical skills and expertise for in-class teaching, we cannot assume these skills and expertise will transfer to other instructional modes, and the sudden changes and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

demanding mode of instruction which many teachers were not trained for proved challenging (Meng et al., 2020; Rossetini et al., 2021). As teachers tried to rapidly adjust their teaching approaches to this new mode of delivery, a practice some science teachers called “Panic-gogy” (Watts et al., 2022, p. 3), many learned that online resources can support learning, but do not suffice as primary learning activities for practical skills; which is particularly significant in secondary school science (Chadwick & McLoughlin, 2021; Rossetini et al., 2021).

Some scholars believe certain disciplines are not suited for remote or online learning, including science, as it is extensively affected by laboratory inaccessibility (Chandrasekaran, 2020; Garcia-Vedrenne et al., 2020; Schirmel, 2021). However, as teachers did what they could to foster scientific literacy during the pandemic, creative approaches to providing practical opportunities emerged, including those revealed in this study and described in Chapter 4. Science education scholars have been clear that teachers should choose approaches that are well suited to the learning goal and task, and Hodson (2014) points out that what might work well for some tasks may be entirely unsuitable for others. However, seeking out effective alternatives to practical and collaborative lab work was challenging. Kelley (2020) noted video alternatives often failed to meet teacher benchmarks for inquiry and authenticity, and although breakout rooms in remote spaces allow students to collaborate and reflect to build conceptual knowledge and develop scientific inquiry and literacy skills, Garcia-Vedrenne et al. (2020) found they were not as effective as in-class collaborative opportunities.

It could be argued that clear direction for teachers to “select appropriate contexts to introduce and reinforce scientific inquiry, the decision-making process, and positive attitudes” (MET, 2000, p. 0.2) may have never collided with a more challenging context: remote learning. With explicit curricular guidance backing them, early in the pandemic, Chan et al. (2020)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

believed science teachers had to shed their fears of trying and practicing new and different pedagogies while teaching remotely, in their attempts to develop student-centered pedagogical toolkits with some form of practical work. As science teachers worldwide responded to barriers to practical learning opportunities amid school lockdowns and restrictions, they were required to adjust student learning activities, and craft new pedagogies through their remote teaching platform, blended teaching situations and in-class but restricted teaching environments. Moreover, from the start of the pandemic, pedagogical decisions were largely left to individual teachers. Zhang et al. (2020) reported that most teachers in China were required to adapt offline teaching content with little experience or online resources. This was also the case in Manitoba, and as teachers worldwide continued their attempts to replicate the experience of practical exposures without proper training, the educational scholarship suggests “not all teachers are good at it” (Patra et al., 2021, p. 163).

Subject-specific knowledge of pedagogy is critical in order for teachers to develop ways of translating their knowledge into effective instructional representation, which under normal circumstances is a complex process (Layton, 1991); doing so during a pandemic considerably exacerbated the task. Teachers were required to immediately adapt to a new teaching paradigm when the pandemic arrived and practical teaching and learning were restricted during “the biggest unplanned educational experiment ever seen” (Soares, et al., 2020, p. 3397). Teaching in this different mode would likely be much more effective if educators had different training and pedagogy, however science teachers were challenged to design effective teaching approaches without formal training or time to research and learn. Approaches found in many educators “teaching toolbox”—laboratory activities conducted every few days, hands-on activities used frequently, demonstrations that regularly relied on student participants, student project work,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

debates, role playing and oral presentations, for instance, had to be set aside or substantively redesigned while teachers crafted new pedagogy. The outcome of this educational experiment is represented in student advancement in scientific literacy, and concerns with the impact on Manitoba students were expressed early on (Stephenson, 2021).

Teachers struggled in their efforts to build effective learning opportunities for students to develop and practice scientific literacy remotely. Early in the pandemic Babinčáková and Bernard (2020), in a study conducted in Slovakia, suggested that experiments done at home were not as enjoyable or effective skill-building substitutes as those done in school, despite teachers putting in their best efforts. As teachers worldwide responded to their new teaching paradigm, they had little choice but to become creatively resourceful. While many teachers successfully co-created new learning activities, standards and expectations with their students while emphasizing increased participation and collaboration (Anderson et al., 2021), I found Manitoba Grade 9 and 10 science teachers were less successful bringing their content to life without viable practical learning opportunities.

With the race for new technology to provide and enhance remote learning opportunities at the forefront of education during the pandemic, teachers worked hard to craft new practical opportunities despite the lack of time to adapt (Daniela & Visvizi, 2022). As science teachers decided what and how they taught during the pandemic, this “stop-gap-solution” (Singal et al., 2021, p. 520) offered opportunity to capture novel pedagogical gains emerging in Manitoba's Grade 9 and 10 classrooms. As I describe in Chapter 4, Manitoba teachers applied multimodal methods and used advanced digital tools and programs, for example, while uncovering alternative resources and supports to promote scientific literacy.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Remote Teaching and Learning

Throughout the pandemic, various terminologies to describe teaching and learning were used such as distance, online, at-home, virtual, emergency, cyber-schooling, and remote, along with variations including blended, hybrid, synchronous and asynchronous (Carrillo & Flores, 2020; ICET, 2020; Manitoba News Releases, 2020, March 31; Safi et al., 2020). In this study, I use the term “remote”, as adopted by Manitoba Education (2022) for teaching and learning in the digital, online, Internet space, where students learned at home while their teachers taught from a different location.

Irrespective of their label, Carrillo and Flores (2020) contend remote styles of teaching and learning bring a specific process to curriculum and pedagogy partnered with the roles, competencies and interactions among all participants. During the period of blended teaching and learning, many Manitoba senior years' teachers taught some of their students in-class, while other students logged in for remote learning from their home, with students alternating between in-person and remote learning every second day. Teachers I spoke with indicated that they found this type of “blended” instruction extremely challenging as it required them to remain visible in front of their computer at all times and engage their learners in-class and at home concurrently. In different blended teaching scenarios, some Manitoba teachers traveled between different classrooms while teaching remotely at the same time—many teachers said that this approach, dubbed “duplex teaching”, was problematic because students felt abandoned without their teachers (Stephenson, 2021, p. 8).

Blended teaching brought challenges for Manitoba science teachers; however, some studies in other settings suggest that it also afforded certain benefits for students. Such positive support for BL was reported early in the pandemic by Puntambekar et al. (2020) as they describe

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the complementary affordances of virtual and physical labs to support student scientific literacy in the US. At the same time, with BL still in its infancy, Graham et al. (2019) identified the need for teachers to develop specialized skills beyond those traditionally required, for its effective implementation.

The term “synchronous” was used to denote scheduled remote classes where teachers and students met at the same time; while “asynchronous” denoted that materials were provided for students to learn on their own (He et al., 2021). Some teachers using BL adopted an asynchronous approach for at-home learners in order to provide authentic experiential learning activities for students who were in class. Other teachers created and relied on “flipped classrooms”, where students learn material provided by their teacher outside of class time and practiced concepts and procedures while in class. Others used a variety of methods, revealing the creative efforts of teachers as they strived for quality teaching (Bhamani et al., 2020). The need for creative pedagogy persisted in Manitoba despite the return to in-class learning for all students, as a number of ongoing pandemic safety protocols in schools remained in place. These protocols continued to restrict experiential learning opportunities that teachers could utilize to promote learning in all disciplines.

As teachers turned to alternative pedagogies when experiential engagement was restricted during the pandemic, learners' experiences and understandings were significantly affected but also significantly different from one another, particularly during periods of remote teaching. As determined in one K-12 case study conducted in the US during the 2020-2021 pandemic school year, many teachers were not trained or prepared to teach remotely, nor were they all good at it; resulting in varied learning experiences for students and wide-ranging conceptual understandings (McKnight et al., 2022). It was additionally noted that teachers lacked training and expertise in

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

using course management systems such as Blackboard or Canvas, which are comparable platforms to Google Classroom or Edsby often used by Manitoba Grade 9 and 10 teachers. I found these platforms to be essential when teaching remotely although I did not find them useful for procedural instruction for science students to conduct practical work.

COVID-19 brought a distinct teaching and learning phenomenon (Gillis & Krull, 2020), with Tomasik et al. (2020) advising “learners are probably the single largest group to experience the pandemic’s indirect effects” while describing studies highlighting the negative effects of remote learning (p. 570). Remote teaching is not just a matter of turning on a camera and going on with business as usual but rather is an instructional mode in its own right requiring specific pedagogical skills and expertise: one that many Manitoba teachers were ill-equipped for in March 2020 (Stephenson, 2021).

Remote Pedagogy in Science Disciplines. Some scholars express the view that hands on activities cannot be conducted online (Humphrey & Wiles, 2021). Others note that the ability to integrate conceptual and procedural knowledge to develop scientific literacy can only be developed through hands-on experience of doing science within a critical and supportive learning environment (Hodson, 2014). Shifting experiments and laboratory activities to virtual platforms was particularly challenging however, as many teachers were unsure how to do this (Babinčáková & Bernard, 2020). Kelley (2020) maintains that in-class laboratory instruction is ideal, and Taylor’s (2020) question early in the pandemic, “how do we teach practical content online, and how do we teach hands-on skills?” (p. 69) persisted. Providing students with scientific practice through virtual environments continued to challenge teachers and researchers (Natale et al., 2021).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Many educators know there is no replacement for hands-on learning opportunities (Bhamani et al. 2020; Hong et al., 2018; Jose, 2017); “Unless one has the laboratory skills to do it, one cannot ‘do science’—at least not well and not successfully” (Hodson, 1993, p. 129). As noted earlier, the prevalent scholarly perspective is that practical activities are required to learn science (Chadwick & McLoughlin, 2021), and providing adequate experiences without access to the tools of an authentic laboratory environment is difficult (Dukes III, 2020). Qualities of scientific literacy including critical thinking, practical knowledge and observation skills are known to develop in part through laboratory experience (Kelley, 2020), posing a challenge to science educators throughout the pandemic as opportunities to foster practical knowledge were limited (Pregowska et al., 2021). While emphasizing that holistic practical learning experiences improve learning outcomes by providing students with opportunity to engage multiple senses and increase sensory and cognitive activity, Gya and Bjune (2021) argue that learning outcomes are compromised in all science education disciplines without in-person laboratory practice where students can interact with specimens, tools and techniques. When COVID-19 restrictions were imposed, Maia et al. (2021) identified difficulties teachers faced advancing functional scientific literacy across all levels of school science in Brazil through periods of remote or hybrid activities. Despite important safety reasons for limiting practical work, the shift in instructional delivery was challenging to all teachers and students (Burgos et al., 2021) and often ineffective and inefficient in the sciences where hands-on practical experiences are required as part of instructional activities (Adedoyin & Soykan, 2020). According to Darling-Hammond and Hyler (2020), these difficulties stemmed primarily from the lack of time to craft and practice new, creative and effective pedagogies to promote scientific literacy. As described earlier, scientific literacy demands practical and transferable skills and attitudes acquired in a well-structured and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

intellectually stimulating lab program (Kyne & Thompson, 2020). Hodson (2014) further emphasized critical components for scientific literacy include the opportunity to practice thinking and acting like a scientist, but such opportunities were replaced by other learning activities during the pandemic; and although alternative teaching strategies kept staff and students safe from COVID-19, the impacts on learning were unknown at the time (Natale et al., 2021). School and post-secondary science educators alike, challenged with the loss of practical learning opportunities for their students during the pandemic seemed to echo the same message. Scholars (e.g., Patra et al., 2021) stressed the magnitude of impact on students' learning when practical work is missing; likewise, Gonçalves and Capucha (2020) argued that the cessation or postponement of hands-on learning is responsible for major irreversible losses in learning and was the greatest educational impact of COVID-19.

One large K-12 empirical study conducted in the US revealed some important general experiences of remote teaching, and that overall, teachers had difficulty providing quality science instruction during the pandemic (Marshall, 2022). According to Marshall, and aligning with the approach taken in my study, the goal of the study was not to 'find fault or assign blame', but rather to understand teacher experiences of remote instruction through this volatile period and the impacts on student learning. Important findings of the study include: over 90 percent of teachers surveyed had never taught online prior to the COVID-19 emergency and fewer than 2% had received any training in remote pedagogy; most of what teachers learned was from each other or personal investigation, as views for online support sites like Microsoft Teams increased six-fold from February to March 2020; and that prior pedagogical training assumed that teaching would take place in a face-to-face environment, leaving teachers overwhelmed with creating new lessons in a way they had never done before. Other important findings include teachers lacked

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

access to various resources, time and direct interaction with their students to do their job well, which resulted in students missing the fundamentals in some subjects—particularly for music, art, and physical education. Arguably similar to science education, Marshall's study showed that despite access to technology, students learning these subjects in isolation often meant learning without peers or appropriate supplies, or being unable to participate in reliable instructional activities. Additionally, it was noted by one teacher in Marshall's study that despite only 9 of their 109 students attending their synchronous lessons held using Zoom, every student was given an A in the course. As shown in Chapter 4, my study results suggest that Manitoba Grade 9 and Grade 10 science teachers faced similar challenges as reported in Marshall's study, which they indicated had a significant impact on teaching and learning during the pandemic.

As previously explained, science education literature at all levels of teaching and learning emphasizes that hands-on sensory input is important for developing scientific literacy (Cutri et al., 2019; Viviani et al., 2021). The post-secondary science education literature supports the challenges instructors and students faced during remote learning and exposes some barriers that may be transferable to senior years science. However, I found fewer studies in secondary science. Although e-learning tools from STEM programs were sought to facilitate the rapid and complex implementation of remote laboratory experiences (Van Nuland et al., 2020) as teachers rapidly tried to include pedagogical innovations in their teaching, however many scholars agree that remote teaching was extremely challenging for instructors of all STEM courses (e.g. Adedoyin & Soykan, 2020; Cheng et al., 2021; Singal et al., 2021). As the COVID-19 pandemic progressed and the suspension of traditional educational activities continued to cripple science educators (Hothi et al., 2022), many researchers conducted empirical research to explore the consequences in science education at all levels. Impacts from the loss of practical learning were

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

central to this research with numerous studies finding that undergraduate chemistry and biology programs were significantly affected by laboratory inaccessibility (Chandrasekaran, 2020). My literature search suggests that these studies far outnumbered studies in K-12 science education settings. Some studies from physics and engineering programs, and from nursing, medicine, dentistry, veterinary school and architecture reveal difficulties instructors faced while switching to remote platforms, as courses were restructured to sustain learning (Garcia-Vedrenne et al., 2020). These studies reveal strikingly comparable findings centered around practical courses that require a lot of hands-on training and practice. These findings from diverse scientific fields are helpful to understanding how restrictions during the pandemic limited opportunities for Grade 9 and Grade 10 students to develop procedural knowledge. As chemistry units and practical work are core to Manitoba's Grade 9 and 10 science curriculum standards, the decisions made and implemented by science teachers in these grades, and their impacts on student learning were of significant interest in this study.

Remote Pedagogy in Post-secondary Chemistry. The post-secondary literature in chemistry education emphasizes the dependence upon practical work to learn this discipline. Despite a wide array of dry lab simulations implemented since the 1970s, chemistry educators have not replaced hands-on laboratory classes (Campbell et. al, 2020). Detailed investigation through practical work is foundational to the critical thinking and analysis necessary for learning chemistry, coupled with authentic wait time for students to think about procedures as they investigate and experiment (Tigaa & Sonawane, 2020). Developing remote strategies to promote scientific literacy in chemistry pedagogy was reportedly difficult and substantially questioned. Chemistry teachers were placed in a particularly tough situation given the practical nature of the subject, and the necessity to shift experiments and laboratory activities to virtual platforms

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

(Babinčáková & Bernard, 2020; Kelley, 2020). Scholars indicate remote chemistry education requires careful planning and a systematic approach that may require months or even years to develop. These findings are further evidence of the necessity of specific training in remote instruction which most teachers in Manitoba did not have in 2020.

Lynn et al. (2020) reported that critical lab activities such as manipulating equipment, working collaboratively, applying chemical hygiene, and evaluating results were difficult to reproduce online, and despite much interest in a variety of simulations, they could not successfully replace hands-on laboratory classes (Campbell et al., 2020). Since students require practice to refine manual dexterity, master proper technique, and to learn to use equipment properly, many science educators maintain that some practical skills cannot be developed through alternate learning activities, such as watching videos or using simulations (Noel et al., 2020), making it particularly significant to find out what alternative approaches teachers implemented, and their perceived effectiveness in fostering scientific literacy.

Numerous scholarly reports suggest remote activities developed throughout the pandemic could not meet laboratory course objectives that require hands-on interaction with equipment and performance of fundamental techniques (Dukes III, 2020; Howitz et al., 2020). When “beakers and pipettes are exchanged for computer screens and keyboards” student participation, collaboration, and development of scientific literacy are compromised (Youssef et al., 2020, p. 3048). Worrall et al. (2020) suggested that carefully designed simulations would help to keep post-secondary students engaged in some of their practical chemistry work in a remote environment, but this was not an efficient approach for learning chemistry. Students enrolled in an introductory chemistry course for non-science majors in the US recognized scientific literacy is not limited to content knowledge and exposed weaknesses in learning science remotely when

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

they stated “it was harder to learn doing simulations... I was clicking on buttons rather than conducting the actual experiments” (Youssef et al., 2020, p. 3049). Nyachwaya (2020) suggested the use of technology to enhance chemistry education at the introductory post-secondary level in the US was previously well documented for the purposes of providing online support material, facilitating student interaction, and bringing students closer to research. Although this existing infrastructure supported the development of remote learning experiences, this replacement did not support laboratory learning objectives that require direct observation of chemical processes (Meng et al., 2020). As the pandemic challenged traditional chemistry pedagogy (Qiang et al., 2020), Kaup et al.'s (2020) proposal that hands-on experience cannot be replaced in STEM-based courses dominated the science education literature.

Several empirical studies from the chemistry field in post-secondary education further support that instructors were particularly challenged in this discipline during the pandemic, as they sought ways to adapt to inaccessible equipment and experiments deemed vital for students to acquire chemistry content knowledge (Reeves et al., 2021). In a study to understand conceptions of US undergraduate chemistry students enrolled in a practical first year university course originally designed to teach laboratory practices, techniques and experimental processes to students in-person, but taught remotely during the pandemic, Reeves et al. (2021) concluded that there isn't a “one-size-fits-all approach to learning” as learning experiences “need to be constructed based on what is being learned” (p. 104320-). Watts et al. (2022) echoed this conclusion in another large US study of undergraduate chemistry students, reporting drastic effects, negativity and weaknesses experienced with the loss of hands-on learning. Previously, a 2020 case study and online survey of post-secondary chemistry students in India and the US had identified that students required step-by-step directions and constant reminders to effectively

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

assimilate chemical concepts remotely, when compared to in-person learning (Tigaa & Sonawane, 2020). The findings of Watts et al. (2022) emphasize that a learner's experience strongly influences how they come to understand the topic, and that experiential engagement is paramount to grasping the nature of science in laboratory education through the conditions, processes and critical thinking of authentic scientific practice where inquiry strategies are core.

Remote Pedagogy in Post-secondary Biological Disciplines. Post-secondary studies in biology are important to this study as they reveal findings that may support the necessity of practical work to learn biology in Grade 9 and Grade 10 science, such as learning the anatomy of plant and animal species in the Reproduction unit in Grade 9 science. Anatomy teachers expressed exceptional concern for student knowledge acquisition amid restricted learning opportunities (Cheng et al., 2021; Singal et al., 2021) as practical sessions and laboratory training are viewed as indispensable—“no dissection, no anatomy” (Cheng et al., 2021, p. 16). Since haptic knowledge is critical to deep conceptual understanding in anatomical science (Longhurst et al., 2020), the great loss of experiential learning during the pandemic was expected to leave learning gaps in the biological sciences (Pather et al., 2020).

Other studies of relevance in biology come from the post-secondary fields of biotechnology, biochemistry and biomedical sciences. Many echo a similar message—while mitigating negative impacts from the closure of educational institutions during the pandemic, remote teaching was unable to effectively replace hands-on practical lessons (Heng et al., 2022). For instance, veterinary instructors in Portugal who attempted to replace parts of practice sessions through remote environments admitted they could not teach the right postures, procedures or how to use instruments correctly without practical work (Gonçalves & Capucha, 2020). Gonçalves and Capucha found the cancellation of hands-on sessions restricted student

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

learning in how to adapt procedures and communicate understandings. Research findings from a study conducted by Heng et al. (2022) in Biomedical Engineering at the Singapore University of Social Sciences revealed concern for imparting laboratory skills through instructor or video demonstration, versus practical learning opportunities. From theoretical and practical student assessments along with a survey, they determined that “students from the COVID-19 generation may be at a disadvantage compared to others with a ‘normal’ education, hindering their entry into the skilled labor market”. Chen (2022) report similar findings from their biomedical study conducted at North Carolina University in the US, which revealed students had misconceptions about the material taught remotely by video and were unable to gain technical skills by performing the experiments in the lab. Chen (2022) maintains that videos cannot adequately replace laboratory learning, as engagement in hands-on manipulation of reagents and equipment is vital, and moreover that students often learn the most by performing a procedure *incorrectly*—something not captured in best-practice videos. I share Chen’s perspective based on my experience as a science teacher where I have observed powerful learning opportunities afforded to students through their laboratory mistakes. In many ways, I also see this as similar to when my children first learned other practical skills such as riding a bike or driving a car. Such errors in practical work are critical for developing functional scientific literacy, and in the post-secondary biomedical sciences when face-to-face learning was replaced with digital learning, such opportunities were not afforded (Low et al., 2022).

In other disciplines such as nursing, medicine, and dentistry programs, students reported great difficulty engaging and learning remotely (Chen et al., 2020; Viviani et al., 2021). Findings from a survey of medical students at Trinity College Dublin, Ireland revealed digital learning without hands-on training and an absence of bedside teaching may have serious implications for

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

student experiences, and for the quality of their education (Low et al., 2022). In another survey conducted in the US, a comparison between two groups of first-year medical students at Rowan University was conducted—those with practical cadaveric learning opportunities, and those with digital anatomy coursework during COVID-19 (Kochhar et al., 2022). Kochhar et al. reported the absence of mandatory dissections in medical education during the pandemic resulted in junior doctors lacking anatomical knowledge, and that in-person dissection skills are necessary for the development of confident physicians capable of making expert decisions. They also noted that the impact resulting from this curricular change is yet unknown. These studies may offer insights into unknown impacts of restricted practical learning in Grade 9 and 10 science for skills and attitudes integral to functional scientific literacy in biology.

Remote Pedagogy in Post-secondary Physics and Engineering. In post-secondary physics and engineering, the transition from traditional face-to-face to online teaching and learning meant “innovations in pedagogy were the need of the hour” (Hothi et al., 2022, p. 11). Physics and engineering faculty were forced to adapt rapidly, were unprepared, and lacked time to plan and necessary tools—all leading to repercussions in student learning. These impacts on student learning were of interest in this study as physics and engineering concepts and practical work to learn them are found in multiple units in Grade 9 and Grade 10 science in Manitoba. From their survey of post-secondary engineering students in India, Hothi et al. further noted that although new tools such as pen-tabs, virtual labs and simulators improved remote teaching throughout the pandemic, they posit that practically oriented programs such as engineering which require a lot of hands-on training will never transmute completely to an online mode. This position was shared by Torres-Freyermuth et al. (2022), who reported scientists and engineers require hands-on experience and practical training, and teaching undergraduate physics students

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in the US about wave mechanics for understanding beach erosion and coastal flooding was challenging for instructors throughout the COVID-19 emergency. These scholars reported research assessing student learning outcomes following virtual training throughout the pandemic showed that the virtual tools were valuable to complement experiential learning and reinforce theory, but less optimal than what can be achieved in a physical laboratory. Of additional interest to this study, according to Torres-Freyermuth et al. (2022) prior studies have revealed the value of playfulness achieved in virtual laboratories has been helpful to engage students in learning. I wonder whether Grade 9 and/or Grade 10 students might have benefitted from novel virtual tools their science teachers were able to access and incorporate into their remote physics lessons.

Further evidence supporting the necessity of practical hands-on experimentation to learning physics was reported by Borish et al. (2022) following a survey of 5000 undergraduate physics students in remote lab courses at 24 US post-secondary institutions during the 2020-2021 academic year. These scholars concluded that some lab goals such as gaining experience to safely operate specialized equipment can only be achieved by working with the equipment itself (Borish et al., 2022), adding that “the world changed a lot during the studied year, but the principles of teaching and learning did not” (p. 18). With hands-on learning serving as the primary objective of some physics courses at Trent University in Ontario, and the hands-on component essential for student success, courses transitioning to a remote format for the 2020-2021 academic year faced lofty challenges (Newman & Stock, 2022). According to Newman and Stock, take-home kits with accompanying video laboratory demonstrations were developed for teaching practical skills in one course, and following its success will be incorporated as a support to the course when in-person learning resumes. The lessons learned from teaching practical courses remotely during the pandemic are valued by Borish et al. (2022) for application to future

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

unforeseen circumstances, to support those with dependents who need a more flexible schedule, for those requiring experience where lab equipment is not available or when disabilities prevent individuals from participating in traditional labs. Although these scholars propose that more research is needed to understand the learning opportunities that remote versus in-person labs offer, they support the latter for learning physics.

In summary, this literature review underlines the importance of practical work for the development of scientific literacy and reveals that a variety of barriers restricted practical work during the pandemic at all educational levels and across various science disciplines. These studies support the value of undertaking this study of Manitoba high school teachers' responses to such diminished practical opportunities. Science education research has shown that scientific literacy is impacted when practical learning opportunities are restricted and calls further research to understand these impacts (Babinčáková & Bernard, 2020; Yan et al., 2021). Such research will help to prepare for future events where practical learning may not be possible (Beauchamp et al., 2021); support learning when students cannot attend school; inform schools with limited resources for practical work; advance teacher knowledge and agency to promote scientific literacy; and offer insights for planning and implementing new curricula.

Chapter III: Methodology and Methods

In this chapter, I discuss the philosophical assumptions underpinning this research which I see as integral to a discussion of the case study methodology and mixed methods research design I used. Additionally, I discuss the methods I used for teacher recruitment, data collection and data analysis; and provide an overview of ethical considerations, and research quality and rigour in this study.

Philosophical Assumptions

Johnson et al. (2007) assert that researchers should adopt assumptions, principles and values connected with the operating research paradigm in their research study. As a novice educational researcher, the philosophical assumptions I brought into this research include a realist ontology and a postpositivist epistemology. I see reality as complex and requiring the use of multiple perspectives to help understand it more completely (Creamer, 2018; Johnson et al., 2007). I believe that demographic diversity and different teacher experience across urban and rural Manitoba contributed multiple perspectives to this research which helped to showcase the experience of teachers in fostering scientific literacy in Grade 9 and 10 science throughout the pandemic. The epistemological belief I applied to this research is that this reality can only be approximated, becoming partially known through research (Creswell & Poth, 2018). As I surveyed and interviewed teachers, and interpreted their experiences, I attempted to accurately reflect their intended meaning. This is the sense in which I understand and enacted objectivity in this study.

As Creswell and Plano Clark (2018) suggest, mixed methods research may draw upon various philosophical positions, but one best stance should inform the research. The philosophy that informed this mixed methods case study is postpositivist. With the pandemic and restrictions

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

to practical learning poised as a prominent background shaping the decisions science teachers made regarding what to teach and how to teach it, meaning in this research was constructed through my analysis and interpretation of data collected through surveys and interviews while relying on definitions of scientific literacy as stated in the literature reviewed earlier. Despite individual understandings of what scientific literacy is, this research was grounded on the understanding that there are certain things teachers should be doing, and certain things students should experience in order to become scientifically literate. I positioned myself in this study with extensive Grade 9 and Grade 10 science teaching practice, experience working with Grade 9 and 10 science teachers and teacher candidates as a practicum advisor, and with remote teaching experience in Grade 9 and 10 science from March through June 2020. I have extensive practical hands-on teaching experience and brought an axiological perspective to this study which includes valuing experiential learning and active learning approaches that promote scientific literacy, as well as a specific notion of what effective science teaching to promote scientific literacy can look like.

With a postpositivist perspective to educational research, Phillips and Burbules (2000) posit “human knowledge is not based on unchallengeable, rock-solid foundations—it is *conjectural*” (p. 26), and “the pursuit of true belief is a regulative ideal rather than an assumption that what is believed at any point in time is certain” (p. 28). Creswell and Poth (2018) note that postpositivist research is framed in multiple perspectives from participants, with the underpinning ontological assumption that a single reality exists beyond ourselves. The reliance on multiple stakeholder perspectives in a postpositivist approach in multiple or mixed methods research and case studies is emphasized by Young and Ryan (2020) who describe postpositivist

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

researchers as primarily objective but also as valuing subjectivity in their efforts to find meaning and build understandings.

I chose to adopt the approach taken by postpositivist researchers following some traditions in empirical science that posit that in order to make a meaningful knowledge claim, studies must be supported by logical reasoning and empirical data that are verifiable. At the same time, these researchers acknowledge that culture, researcher axiology and other surroundings influence our perception of the world (Lederman & Abell, 2014). Wildemuth (1993) explains value in this approach advocating a type of methodological pluralism that allows the researcher to address their research questions through a combined positivist and interpretive lens, despite these two approaches taking very different views of the nature of reality and how one comes to know about or understand that reality. Wildemuth also describes case studies conducted with a postpositivist approach, suggesting this approach allows the researcher to address different specific research questions which not only contribute to the understanding of a general research problem, but richly inform it. Other scholars who approach case study from a postpositivist perspective include Harrison and McCaig (2017), who conducted a reflective case study in the UK on approaches in educational research through this lens. Findings of their case study relied on evidence and inference and the case produced useful insights for educational research. With the primary concern of postpositivist research to provide a rational explanation for educational phenomena (Lederman & Abell, 2014), I see this approach as aligned with the purpose and research questions of my study.

Offering common research designs adopted in postpositivist research, including large-scale surveys, Lederman and Abell (2014) describe how objective, logical empiricism can support research designs that aim to explain what is happening within an education program or

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

system, and why. Lederman and Abell explain that postpositivist research is objective, and educational researchers operating with this view and assumptions attempt to “systematically approach the truth as best as they can, in order to inform the people of interest (teachers, policy makers, etc.) to help make wise decisions” (p. 4). Through descriptions of studies collecting empirical data to objectively compare different teaching methods, Lederman and Abell (2014) also explain the postpositivist tradition focuses at least on correlational explanation, such as the influence of teachers on a particular student outcome. Along similar lines, my study used a case study methodology to seek understandings of the pedagogical decisions of teachers during the pandemic, and insights into teachers' views of their impacts on student scientific literacy development.

The question “can and should educational inquiry be scientific?” raised by Phillips and Burbules (2000) is answered by the current postpositivist view that “social science and educational research can, and ought, to be scientific” (p. 65), as “it is not the *type* of research that makes it scientific” (p. 86), but rather the researcher's assumptions and interpretive framework to draw conclusions from it. With this in mind, while firmly grounded in the literature on scientific literacy and experiential and active learning theories, I was guided in this study by a postpositivist approach, based on seeking appropriate evidence for conclusions, all the while remaining open-minded to conclusions discovered in the data, as Phillips and Burbules suggest.

Case Study Methodology

Case study research served as the principal methodology for this study. Creswell and Poth (2018) consider case study methodology as a leading approach in the education field. Many scholars advocate this research approach including Merriam and Tisdall (2015), Saldaña (2016) and Yin (2014), as case study research is noted as a common methodology for understanding

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

complex phenomena. Creswell and Poth (2018) point out that intrinsic case studies are useful for studying unusual or unique situations. I consider teaching science and fostering scientific literacy during a global pandemic when different restrictions to in-person teaching and learning were in place to be an unusual situation.

Case studies are defined by Yin (2014) as an “empirical inquiry investigating a contemporary phenomenon (the case) in-depth within its real-world context” (p. 16), and, along with a qualitative focus, it can also support a quantitative component. Yin further suggests a real-world context is the primary reason for selecting a case study approach. I believe that teaching and learning during the COVID-19 pandemic provides such a context. Merriam (2008) offers that case studies are descriptive and moreover heuristic, supporting the educational potential of this methodological choice. By heuristic, Merriam means the data should reveal information relevant to the study while stimulating the reader to think beyond the information to application (Merriam & Tisdell, 2016). I see this as an important vision for my study. Furthermore, Creswell and Poth (2018) view case study research as a qualitative approach to explore a real-life, contemporary bounded system (case) through in-depth and detailed data collection from multiple sources of information such as interviews, documents and reports.

Bound by the parameters of place—high schools in Manitoba; time—the COVID-19 global pandemic that began in March 2020 and officially ended in May 2023 (WHO, 2023); and event—teaching Grade 9 and 10 science with restrictions to practical learning, I chose to use a case study methodology. As each Canadian province develops and implements its own science curriculum standards, Manitoba Grade 9 and Grade 10 science courses are framed by the Manitoba Education Senior Years Science curriculum standards document. As previously described, the COVID-19 pandemic is a well-defined period of time with significant pedagogical

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

disruption and therefore, is of particular interest. Finally, as noted earlier, Grade 9 and 10 science are the final two mandated general science courses in the province. They provide a final opportunity for students who do not take higher level elective science courses to develop competencies that support scientific literacy. As such, I see science pedagogy during this time as an event of distinct interest and importance. In summary, this research is a case study of the pedagogical response of Manitoba Grade 9 and Grade 10 science teachers during the COVID-19 pandemic, to find insights of teachers' views on the potential impacts of their pedagogical decisions on student development of scientific literacy concepts, skills and attitudes.

Mixed Methods Research Design

In this study, data collection, analysis, and final conclusions were framed on postpositivist assumptions. Greene's (2007) view of a mixed methods way of thinking as "generative and open, as researchers seek richer, deeper, better understanding of important facets of our infinitely complex social world" (p. 20) underpins my thinking behind the methodology of this study. Aligning with a postpositivist paradigm, Creswell and Plano Clark (2018) offer a definition and core characteristics of mixed methods research as: collecting and analyzing both qualitative and quantitative data; integrating the two forms of data and their results; and organizing and framing research procedures within theory and philosophy. Many researchers turn to mixed methods when quantitative results alone will be unable to provide a complete understanding of a research problem, and further data is needed to help explain the results (e.g., Bazeley, 2018; Hesse-Biber & Johnson, 2015; Teddlie & Tashakkori, 2009) among others.

As a mixed methods approach is based on assumptions that various legitimate approaches to social inquiry exist, and as any given approach is inevitably partial, multiple approaches can generate greater depth of understanding of a phenomenon (Greene, 2007). Bazeley (2018)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

advises that multiple methods are often required to understand the complexity of social issues. Advocates for this question driven approach, including Hitchcock, think a mixed methods approach often helps them find the fullest answers, while the questions dictate the research design (Hesse-Biber & Johnson, 2015). Other scholars, including Bazeley (2018), Doyle et al. (2019), Greene (2007), Hesse-Biber and Johnson (2015), and Teddlie and Tashakkori (2009) reinforce the necessity of using a mixed methods research design when multiple research components or phases are needed to answer the research problem. I contend that this is the case in my study.

Of particular interest to me is Bazeley's (2018) perspective that mixed methods is a generic term for any research that involves multiple sources and types of data and/or multiple approaches to data analysis. Bazeley is not insistent that mixed methods research rely on a "quantitative" and "qualitative" method, but rather "could be two methods that people call qualitative" (p. 2)—making the point that the distinct separation between the two components can range significantly along a quantitative-qualitative continuum. Some researchers in fact extend beyond this quantitative-qualitative continuum to employ two qualitative components in their mixed methods research to obtain a more comprehensive understanding of a phenomenon from differing perspectives, when two data sets regarding particular aspects of a phenomenon are required from those experiencing the phenomenon (Hesse-Biber & Johnson, 2015). Regardless of the choice of methods selected, using a mixed methods design is important when multiple sources of data will help support the study and answer the research questions (Bazeley, 2018). Greene (2007) provides an additional rationale for a mixed methods design relevant for this study: "If it is important to gauge both the frequency and intensity of a phenomenon *and* its experiential meaningfulness, it simply makes good methodological sense to use both a survey

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

and a case study design” (p. 28). Of further relevance to this study, Hesse-Biber and Johnson (2015) suggest a qualitatively sequential mixed methods design is useful to gather quantitative descriptive information, like demographic statistics of the population in the study, so the findings of the core qualitative study can be situated within a larger context.

Finally, regardless of the independent nature of the components, of great significance to mixed methods research is some form of data integration to draw final conclusions. Scholars suggest the multiple components must engage in conversation with one another at the analysis level to allow for a more complex understanding of the research problem (Bazeley, 2018; Doyle et al, 2019; Hesse-Biber & Johnson, 2015). As much of the mixed methods research scholarship focuses on the systematic integration of quantitative and qualitative methods in a single study in order to obtain a fuller picture and deeper understanding of a phenomenon (Johnson et al., 2007; Mat Roni et al., 2020; McKim, 2017), it is important to understand ways that this integration might occur. I appreciate Bazeley’s (2018) suggestion that quantitative approaches to research focus on measuring or estimating the quantities of things while qualitative approaches to research focus on interpreting and describing their qualities. Most mixed methods scholars assert great flexibility with this approach, where the wide ranging qualitative-quantitative continuum allows a study to be located at any point along the continuum, or at either end (Bazeley & Brindle, 2015; Creamer, 2018; Teddlie & Tashakkori, 2009). Examples of such an approach are seen when quantitative findings from a large sample and set of closed-ended questions are nested or embedded within a qualitative small sample and open-ended approach, to allow for a more robust understanding of the phenomenon and support stronger conclusions than those possible with a single method (Creamer, 2018; Hesse-Biber & Johnson, 2015). Although Hesse-Biber and Johnson (2015) relay concerns that many mixed methods studies remain “unmixed, with little

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

interaction between the two methods” (p. xli), scholars including Buck et al. (2009) describe how quantitative and qualitative components are effectively integrated for stronger conclusions in the mixed methods sequential explanatory design used in their study. I adopted a similar approach for integrating the data from the two phases of my study.

Numerous advantages to utilizing a mixed methods research design, reported by Creswell and Plano Clark (2018) were realized in this study: more evidence for the research problem was obtained through different but complementary data on the same topic, achieved through the Phase I survey and Phase II interviews; limitations of a solely quantitative or qualitative approach were offset as neither Phase I nor Phase II data collection methods provided ample data to answer the research problem; synergistic insights going beyond quantitative or qualitative approaches emerged, as integrating the Phase I and Phase II results provided deeper insights than the individual results of each phase; and finally a mixed methods research design offered opportunity to use several possible methods to address the research problem and valuable opportunity to use both numbers and words to answer the research questions.

Despite considerable debate among mixed methods scholars and the evolving view of this research design in recent decades, it is agreed that better understanding of the multifaceted character of education can be reached through multiple approaches in research (Greene, 2007). As such, the research design for this study had two phases which I saw as necessary to adequately answer the research questions: survey results were important to the initial phase of this research, and data from interviews were critical for enhanced understanding of the research problem in the second phase. Although a wide array of typologies and mixed methods designs are reported in the literature (e.g., Creswell & Plano Clark, 2018; McKim, 2017), the case selection variant of the sequential explanatory design is the core design I utilized (Creswell &

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Plano Clark, 2018; Teddlie & Tashakkori, 2009). Accordingly, Phase I of this mixed methods case study mainly sought to find what scientific concepts, skills and attitudes teachers prioritized before and during the pandemic, while Phase II investigated the pedagogical decisions reflecting teachers' adjustments during the pandemic. Drawing on Teddlie and Tashakkori, I see these as distinct exploratory and explanatory phases. The integrated analysis of both sets of data provided insights into the potential impact of teachers' decisions on the advancement of student scientific literacy. The results from the first phase provided a general understanding of the research problem; while the results from participant interviews helped me to expand and explain the survey results to provide a deeper and more nuanced understanding of the research problem.

Methods

Two phases were used in this mixed methods sequential explanatory case study design. In the first phase, data was helpful to mainly answer the sub-questions:

1. What curricular units and learning outcomes did Manitoba Grade 9 and Grade 10 science teachers prioritize prior to and during the COVID-19 pandemic?; and
2. Which Grade 9 and 10 science learning outcomes were taught through practical work prior to the pandemic and which ones were taught through alternative activities amid school lockdowns and restrictions during the pandemic?

Data in this phase was collected through an anonymous online survey open to all Manitoba teachers with experience teaching Grade 9 and/or Grade 10 science prior to and during the COVID-19 pandemic. I conducted the survey between September 1, 2022 and October 21, 2022 and 58 teachers responded.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

In the second phase, data from a sub-set of teachers who had responded to the survey ($n=11$) with experience teaching Grade 9 and Grade 10 science was collected through follow-up interviews. This data mainly helped to answer the sub-questions:

1. In what ways did teachers limit and/or adjust practical learning opportunities for Grade 9 and Grade 10 science students during the pandemic?; and
2. How did teachers perceive alternatives to practical work allow them opportunity to effectively promote scientific literacy?

Although data primarily from Phase I was helpful to answer the first two sub-questions, and data primarily from Phase II helpful to answer the final two sub-questions, in mixed methods research the data is integrated. Consequently, some data collected in each phase was useful to answer sub-questions in both phases. An overview of sub-questions (shortened for the table) addressed in each phase of this study, in association with numbered questions from the two research instruments is presented in Table 1.

Table 1

Research Sub-Questions Addressed by Phase I and Phase II Research Instruments

Phase I Survey Questions (S ✓)	Phase I Sub-Questions				Phase II Sub-Questions				Phase II Interview Questions (I *)
	Units/LOs prioritized prior to/during pandemic?		LOs taught via practical work pre- pandemic/alternative activities during?		How do teachers limit/adjust practical work during the pandemic?		How do teachers perceive alternatives effectively promote SL during the pandemic?		
	S	I	S	I	S	I	S	I	
1	✓	*		*		*			1
2	✓	*							2
3	✓	*		*					3
4	✓	*		*					4
5	✓	*		*		*			5
6	✓	*		*		*			6
7	✓					*			7
8	✓			*		*			8
9	✓	*		*		*		✓	9
10	✓					*			10
11	✓	*				*		✓	11

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

12	✓			*		*			12
13			✓			*			13
14			✓		✓	*		*	14
15	✓		✓	*		*			15
16	✓	*	✓	*	✓	*		*	16
17	✓		✓					*	17
18	✓		✓		✓			*	18
19	✓		✓			*			19
20	✓		✓		✓	*		*	20
21			✓		✓		✓		
22	✓		✓		✓		✓		
23	✓		✓		✓				
24							✓		
25	✓		✓						
26	✓		✓		✓		✓		
27	✓		✓						
28	✓		✓		✓				
29	✓		✓						
30	✓				✓				

Following data analysis of each independent phase, an integrated interpretation of the two forms of data and their results was conducted. The methods and rationale for each step of data collection and analysis are elaborated on, following a brief overview of ethical considerations in this study.

Ethical Considerations

Ethical considerations for all stages of this research along with a plan to address any anticipated concerns were required. This research addresses three ethical principles: respect for persons, concern for welfare, and justice (Van den Hoonaard, 2019). My completion of the Tri-Council Policy Statement Course on Research Ethics (TCPS 2: CORE), Privacy Training for Researchers (PHIA), and submission of the University of Manitoba Research Ethics Board (REB) Protocol Submission Form were critical first steps addressing respect for persons, concern for welfare and justice. Ethical considerations in Phase I and Phase II, specific to participant recruitment, data collection and data analysis are described in context. In consideration of the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

COVID-19 pandemic and the safety of all participants, all phases and steps of this research were conducted remotely.

Recruitment of Participants

Grades 9 and 10 teachers in all 38 Manitoba school divisions were invited to participate in the first phase of this mixed methods case study. An invitation was sent to school divisions, via email, to recruit teachers to participate in the first phase of this study through an anonymous survey; along with an invitation for teachers to participate in a follow-up interview in Phase II. Emails to all of the 38 Manitoba school division superintendents to introduce and explain the purpose of the study, along with informational and consent letters for participants were sent out after research ethics approval was obtained (Appendix A). The email included a request to distribute invitation letters to all science teachers with teaching experience in either Grade 9 or Grade 10 science prior to and during the COVID-19 pandemic. Permission for teachers to participate in this study was granted by 21 superintendents; 11 superintendents did not respond despite a follow-up email and phone call invitation; and six superintendents did not allow their teachers to participate. Consent for participation in the Phase I anonymous online survey and confirmation of science teaching experience in Grade 9 and/or Grade 10 science in Manitoba was collected digitally through SurveyMonkey when teachers opened the survey link. The invitation to participate in the Phase II follow-up interview specified inclusion criteria for teachers with experience teaching Grade 9 and 10 science, prior to and during the pandemic. This approach aimed to yield a diverse group of Phase II participants to best serve the research questions and aims (Creswell & Plano Clark, 2018). Electronic documents for the Phase II interviews were provided for participant consent and signature and were collected via email. An electronic scan, or photograph of the consent form with hand-written signatures was accepted as informed

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

consent through teacher email. A request was made for teachers to respond within a two-week period to participate in Phase II of the study; and two follow up emails were sent to each school division after one and two weeks of the first email, respectively.

Development and administration of the Phase I survey guided by Vannette and Krosnick (2018), Toepoel (2016), and Sullivan and Artino (2017) afforded improved coverage of the intended population and the advantage of self-administration (Vannette & Krosnick, 2018) along with low costs and quick participant responses (Toepoel, 2016). I considered the recommendations of these scholars as I created the survey. Notably, according to Vannette and Krosnick (2018) when surveys are well-designed, they are a trusted method of data collection capable of capturing high quality data. I aimed to reach a large open-ended population sample with the survey. However, the size of the sample obtained was influenced by many factors, including the September through October dates when the survey was made available. This is a time of year when teachers can be quite busy, which may have been exacerbated during the pandemic. To estimate how many teachers met the inclusion criteria to participate in the survey, I reviewed the September 2020 summary of Senior Years Enrolment for grades 9-12 and learned there were 63,185 students spanning the four grades (Manitoba Education, 2020). I reasoned that if approximately half of these students are Grade 9 and Grade 10 students—perhaps totalling 30,000; and with average class size reported in Manitoba to be 25-30 (MacLean, 2020), at most, 1000 teachers might teach Grade 9 and 10 science in Manitoba. When the survey closed, the total of 58 responses submitted over a period of two months were fewer than expected—yet sufficient to derive meaningful descriptive statistics (Shi & McLarty, 2009) related to the Phase I sub-questions. The survey participants taught in school divisions in urban Winnipeg, other urban centers, or in rural Manitoba.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

In keeping with recommendations for this mixed methods case study methodology, an open-ended number of teachers were invited to participate in Phase I, while a closed-ended sample was sought for Phase II of this research (Creswell & Poth, 2018). Following Merriam's (1998) recommendation that a minimum of ten participants who experience a phenomenon are necessary for in-depth interviews in any case study; ten participants were sought to inform the Phase II sub-questions. Collecting sufficient qualitative information to identify meaningful themes and a range of explanations for the Phase I results was an important consideration in Phase II (Creswell & Plano Clark, 2018). Teachers with experience teaching both Grade 9 and Grade 10 science were sought to offer common, yet different information in both courses and offer additional perspectives of student readiness to advance between Grade 9 and Grade 10 science. A total of 11 science teachers across Manitoba with experience teaching both Grade 9 and Grade 10 science prior to and during the pandemic volunteered to participate in a Phase II interview after the four-week response period. All 11 volunteers were included in the study. These 11 teachers taught in eight different Manitoba school divisions, four in urban centers and four in rural communities.

Hesse-Biber and Johnson (2015) indicate that a Phase II subset sample such as this can allow for readily generalizable results, while also directly linking the two phases of the study. However, since responses to the Phase I survey in my study were anonymous, I was unable to link survey responses to the interview participants. Following the 11 interviews, I felt that I obtained sufficient explanations for the Phase I data, legitimizing a stopping point for category and theme development (Morse et al., 2021).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Data Collection

The Phase I data collection process was completed anonymously by teachers through a SurveyMonkey questionnaire administered through my personal, paid university student account with password protected enhanced security and IP blocking enabled. The SurveyMonkey questionnaire consisted of seven demographic questions and thirty closed-ended questions (Appendix B). The survey required approximately 10-15 minutes for teachers to complete. The questionnaire was designed to primarily inform the central research question, and the two Phase I research sub-questions.

The informational email sent to Manitoba school divisions for distribution to participants included the anonymous survey link, with a survey start and close date. Follow-up phone calls were placed to school division offices after two weeks, and a second follow-up email with the link was sent to the school divisions three days prior to the survey close date, as a reminder. Superintendents from 21 of Manitoba's 38 school divisions confirmed distribution of the link to their Grade 9 and Grade 10 science teachers, by phone call or email. While 11 superintendents of the remaining 17 school divisions did not respond, six superintendents decided not to distribute the information to teachers in their division.

All data collection and data storage complied with University of Manitoba Research Ethics Board (REB) requirements, and the survey data was secured and protected through my SurveyMonkey plan and saved on my University of Manitoba OneDrive account for analysis.

Phase II semi-structured interviews were guided by an interview protocol with twenty questions (Appendix C) developed deductively from the relevant science education literature and Manitoba Senior Years Science curriculum standards to collect data to answer the Phase II research sub-questions. The Phase II interview protocol was set in advance to answer the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

research questions and was not dependent on the Phase I results. The interview questions related directly to pedagogical decisions about student opportunities in Grade 9 and Grade 10 science to learn scientific literacy concepts, skills, and attitudes, as per field specific definitions in the relevant literature, and as framed by experiential and active learning theories. As qualitative research often requires asking participants open-ended questions in which they have opportunity to freely share their experiences and views (Creswell & Poth, 2018), the interview questions were designed accordingly. Further, when participants were asked questions scripted in the interview protocol during the one-hour remote session, whenever they offered additional information while openly answering each question, fewer questions were required; in other instances, further probing was necessary.

Interview data was collected from the 11 participants through my University of Manitoba Zoom account. The interviews were recorded to the cloud for Zoom auto-transcription, but participants had the choice to keep their videos off during the interview. Digital recordings of the interviews were encrypted and stored in my University of Manitoba OneDrive account for data analysis. The interviews were auto transcribed verbatim and checked for accuracy against the digital recording. I made field notes following each interview, and memos were entered electronically in the margins of the interview transcripts. A copy of their transcribed interview was provided to each participant by email, and they were given the opportunity to make changes within two weeks. One participant responded with a ratifying comment, but none responded with concerns or requested changes to their transcript.

Interview participants were invited to participate remotely in this study for their protection, as in-person interviews during the pandemic presented health risks. Also, I considered that interviewing remotely made it easier for participants from afar to contribute their

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

perspective. Interviews were scheduled in advance with each participant as suited to their schedule, and each interview took between 50 and 60 minutes. I assigned numbers to the 11 participating teachers (E.g. Participant 1, [P1]), for use in the direct quotes and in writing about this research, in order to shield participants' identities as agreed in the consent process. Participants were assured that their engagement in the study was voluntary and that they could withdraw from the study if they chose, at any point before writing of results began. Electronic transcripts, field notes and memos, along with digital recordings of interviews were all encrypted and stored securely on my University of Manitoba OneDrive storage, and the interview recordings were destroyed following data analysis.

A twenty-dollar gift card was provided to each interview participant for their participation in Phase II of this study. After data analysis was completed and no further communication was required with the Phase II participants, a summary of results was sent to each participant by email. Although participants were given a two-week response period for feedback or questions related to the summary, no responses were received.

Data Analysis

Analysis of the quantitative Phase I data and qualitative Phase II data were first conducted independently, prior to an integrated analysis. Data analysis in this study was coupled with data collection throughout the entirety of the study following Merriam's (1998) suggestion. As such, field notes and memos were made concurrently throughout data collection and analysis in the quantitative and qualitative phases of this study.

Phase I Analysis. In Phase I, 58 Manitoba Grade 9 and/or Grade 10 science teachers responded to the survey over a two-month period in the fall of 2022 through SurveyMonkey. I examined the file in SurveyMonkey and converted it into a pdf file for data analysis. I conducted

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

descriptive statistics for the basic features of the demographic data (questions 1-7), to provide simple quantitative descriptions of the participants in keeping with Shi and McLarty (2009) and Teddlie and Tashakkori (2009). To describe the demographic data, I tallied response numbers to determine the percentage of the respondent population for each response option in demographic questions 1-3. I calculated the mean, mode, and percentages of the respondent population for demographic questions 4-7. I then examined the demographic data against the survey research responses, for correlations or patterns between demographic subgroups with different: science teaching experience, scientific discipline expertise, geographic community, and Grades 9 and/or 10 science teaching experience prior to or during the COVID-19 pandemic. Since patterns between group' responses were not apparent, analysis between the different subgroups was not conducted. The few responding novice teachers for example did not respond differently than participants with greater experience, so the research data from all participants was analyzed and reported collectively. As descriptive statistics in mixed methods research allow for easily interpretable tables and summaries to detect patterns and better communicate results (Teddlie & Tashakkori, 2009), they were of further value to the analysis of the survey research data. I utilized SurveyMonkey descriptive statistics for the survey research data (questions 1-30) including mean, mode, and the percentage of the respondent population, and double checked with calculations by hand to ensure accuracy. I printed and analyzed the data for broad trends, conveying descriptive statistics for the basic features of the research data in tabular form (Hoy, 2010).

For the analysis of survey research questions 1-12, I calculated the mode and the total responses to each question and the percentage of the respondent population; in questions 13-24, mode, mean and percentage of respondent teachers were determined from the total responses to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

each question, and a number was assigned to each response (1, 2, 3, 4...) to support these descriptive statistics as guided by Creswell and Plano Clark (2018); in questions 25-30, the total number of responses to each item were used to calculate the percentage of participants responding to each item. Additionally, questions 25-26 were temporally paired to gather pre-pandemic and pandemic data and were further described by calculating the change in teachers' responses pre- and during the pandemic. The data was then analyzed with reference to the research questions and represented in text and tables (Creswell & Plano Clark, 2018). The survey findings were helpful to answer the two Phase I research sub-questions, for informing the integrated analysis, and for answering the main research question.

Phase II Analysis. The Phase II data collected through 11 semi-structured interviews were analyzed in timely conjunction with data collection, which was helpful for maintaining research trustworthiness: credibility, transferability, dependability and confirmability (Creswell & Plano Clark, 2018; Saldaña & Omasta, 2018; van Manen, 2014). Analysis of the Phase II data was guided mainly by mixed methods scholars Creswell and Plano Clark (2018), Hesse-Biber and Johnson (2015) and Teddlie and Tashakkori (2009); and qualitative research scholars Morse et al. (2021), Saldaña (2016), Corbin and Strauss (2008) and Bogdan and Biklen (2007). In my opinion, these scholars recommend similar approaches to qualitative data analysis, such as ways to organize, code and categorize data and to identify themes and meaning in the data.

Following each interview, I checked the Zoom autogenerated transcriptions for accuracy by listening to the recordings while reading each transcription. The resulting edited transcriptions from the 11 one-hour interviews ranged in length from 7352 to 10,761 words, with transcription notations included: italics for verbal emphasis; and verbal descriptions of participant gestures or text clarification within square brackets. Field notes were generated electronically after each

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

interview from initial jottings to facilitate my memory of the session, and contained the date, time, and participant details as suggested by Saldaña (2016). I added observer comments (O.C.) to ensure timely capture of important emphases expressed by participants (Bogdan & Biklan, 2003) and to document my immediate responses, interpretations and questions (Saldaña, 2016). Saldaña suggests that insights from written documentation of participant observation in field notes from qualitative research are “potential sites in which rich analysis can occur” (p. 45). An example of a field note I wrote is:

This teacher taught all four units in Grade 10 science for several years, so it was surprising to hear they hadn't taught any of the Weather SLOs during the pandemic. They also seemed very self conscious about mentioning this—perhaps comparing themselves to other teachers, or wondering how I perceived this?

The transcript data was then formatted in a Word document with extra wide margins to accommodate electronically written memos. After transcripts were printed to aid in analysis, read, and re-read to obtain a sense of the data, memos about my initial thoughts were recorded in the transcript margins based on the suggestions of Creswell and Plano Clark (2018) and Morse et al. (2021). Saldaña (2016) suggests such memos,

Should read like letters to a close friend, a journal or a lab notebook, and valuable private and personal researcher musings, informed hunches, “ah-ha” moments of insight, and intuitions that are question-raising, connection-making, and answer-generating can lead to a richer and more powerful explanation of the study's setting, context and participants. (p. 44)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Thornberg and Charmaz (2014) inform that memo writings provide the researcher with an “intellectual workplace” to help work toward a solution to their research problem. As such, I utilized memos to refine interview questions for each subsequent interview. Many qualitative research methodologists agree that whenever *anything* related to coding or the analysis of data comes to mind, researchers should write a memo about it immediately, with a goal not to summarize data but rather to reflect and expound on the data (Saldaña, 2016). Saldaña adds that these reflections can guide the coding process and might include: How the researcher relates to the participants and/or the phenomenon; the participants' routines, roles and relationships; code choices and their operational definitions; problems with the study; personal dilemmas with the study; emergent patterns, categories and themes; and tentative answers to the study's research questions. An example of one memo I wrote was:

As I reflect on their comments, this teacher seemed to be particularly emotional when answering questions about how many clusters and SLOs they taught during the pandemic. Their strong position is shared by several other participants. I wonder what the *average* response might be if all Manitoba grades 9 and 10 teachers responded—does a qualitative mean exist?

Both memo writing and coding are concurrent analytic activities, but while memos are “sites of conversation with ourselves about the data” (Saldaña, 2016, p. 44), codes are researcher-generated constructs, most often a word or short phrase applied to the data that symbolize a summative, evocative or essence-capturing attribute to translate the data, and form the critical link between data collection and the researcher's explanation of meaning. As such, following my initial immersion and free “brainstorming” with the data (Corbin & Strauss, 2008), I completed memo writing for each interview transcript, and began coding while interviews were

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

still underway by developing codes to conceptually capture what the data described (Morse et al., 2021). Saldaña (2016) informs that since researchers bring their personalities, predispositions, subjectivities and even quirks into the process of coding, judgment is required, and researchers should only code relevant text that surfaces in the data. Saldaña also indicates coding prompts deep reflection and attributes complex interpreted meaning to each individual datum, allowing codes to eventually become part of a broader scheme of classification as they are placed into categories which subsequently evoke greater themes or higher-level concepts.

In this study I developed some codes from the exact wording of the participants (Creswell & Plano Clark, 2018) while composing others deductively drawing on the science education literature regarding scientific literacy and practical learning, and the curriculum documents; or inductively drawing on my positionality as a Grade 9 and Grade 10 science teacher and science education doctoral student. Saldaña's (2016) view that qualitative researchers often encode major units of social organization including occupational tasks and roles like teacher and student was also considered in code development and grouping. Codes that I developed from participants' exact words and grouped together as teacher experiences for example, include difficulties, concerns, mental health and physical health. Deductive logic, though less frequently relied upon in qualitative analysis compared with inductive reasoning (Teddlie & Tashakkori, 2009), propped the development of several codes. Examples of codes I developed deductively against the relevant science education literature include scientific literacy, curriculum, skills/attitudes, unit/cluster, SLOs, and GLOs. Examples of codes I developed inductively include pandemic mode, priorities, alternatives, knowledge gaps and benefits.

Creswell and Plano Clark's (2018) suggestions were additionally useful: reviewing field notes and memos are helpful to seek broad trends in the data, and coding ideas by grouping

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

evidence to reflect increasingly broader categories can provide the necessary perspective to answer the research questions. As such, after reviewing all the data, field notes and memos, I created a qualitative codebook in tabular form with code descriptors (Creswell & Plano Clark, 2018). I then coded the qualitative interview data in the participant transcripts, one transcript at a time. According to Morse et al. (2021) qualitative researchers code data “word by word, line by line, and clump by clump to conceptually capture what is happening in the data” (p. 5). Utilizing such qualitative approaches, line by line coding, or first level coding was applied to this data as meaningful words and phrases were highlighted with different colours, and appointed codes were added to previously written memos written in the margins. Codes were applied to phrases, sentences or groups of sentences within the data that shared a common idea. Following the advice of Corbin and Strauss (2008), the significant time I spent with the data to gain insights into grouping ideas conceptually was vital in code development and in early analysis and helped me to prevent hasty conclusions that might prove wrong as analysis proceeded.

Drawing strategies from qualitative research methodologists, I coded the data using a constant comparative method (Corbin & Strauss, 2008) or repetitive process often used by researchers to engage with all of the data while checking emerging interpretations (Hunter et al., 2005). This process is generally described as ongoing analysis while data collection continues (Teddlie & Tashakkori, 2009), and when researcher interpretations change as more data is gathered. So, while coding the transcripts, I compared each subsequent transcription against those previously coded, in cyclic fashion, which in turn helped guide the coding process (Saldaña, 2016). As I read and re-read the interviews in their entirety while reflecting on them as a whole, I modified some codes in the process. Following the guidance of Bogdan and Biklen (2007) who recommend limiting codes to 30 to 50, 39 codes were originally created after reading

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

then re-reading the transcripts. Three were dismissed on further analysis while another two were added, resulting in 38 codes used in this study. As listing codes and assigning an abbreviation to each code is considered helpful to analysis (Bogdan & Biklen, 2007) abbreviations were created for the 38 codes used in transcript analysis. After first level coding, codes were grouped by type in light of the research questions as qualitative research scholars suggest (Morse et al., 2021), and initial code groups were categorized systematically to describe emerging ideas and descriptive categories.

Interconnections between the categories were sought as certain patterns and linkages emerged, primarily via frequency, omission, or similarity. Identifying codes used frequently in data analysis allowed repetitive patterns in what participants talked about and repetitive occurrences in their daily lives to become consistencies documented in the data, and trustworthy evidence for my findings (Saldaña, 2016). As categories were finalized and ultimately interrelated into a set of seven themes (Creswell & Plano Clark, 2018), evidence for the emergence of themes is described. To provide this evidence, I relied on the direction of qualitative scholars (e.g. Creswell and Plano Clark, 2018; Lingard, 2019; Younas et al., 2023) to use specific quotes from individual participants, to share multiple perspectives showing divergent views, and to use thick description. Once all of the qualitative data had been analyzed, the major qualitative findings were summarized and interpreted in light of how they answered the Phase II research questions.

Integrated Analysis. In the next stage of analysis, the two sets of results in this mixed methods case study were integrated for interpretation, to identify how the Phase II results helped to explain and extend the Phase I results, and how both, together, answered the central research question (Creswell & Plano Clark, 2018). Creswell and Plano Clark (2018) emphasize the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

integration of quantitative results with the sequential follow-up qualitative phase is critical to an explanatory sequential mixed methods design, however they also note that some researchers will report their study with a distinct quantitative and sequential qualitative section to provide clarity for readers. I chose to adopt this delineated approach in this research study, while attempting to reflect the true value of mixed methods research to generate additional insight beyond those gleaned from strictly separate quantitative and qualitative results seen in multi-methods research (Creswell & Plano Clark, 2018). Creswell and Plano Clark propose data analysis of each independent research phase followed by an integrated analysis examining the interface of quantitative and qualitative results can yield deeper understanding of the case, as personal experiences are used to help explain and expand on Phase I results. As such and guided by the collective advice of research scholars, analysis of the Phase I and Phase II data were conducted sequentially but independently followed by an integrated analysis of the two phases grouped according to the research questions.

The procedural steps for data analysis integration used in this study included: comparing quantitative and qualitative results to find common concepts across both sets of findings; determining how results confirm, disconfirm or expand each other; and advancing interpretations of how the confirming, disconfirming, and/or expanded evidence enhances understanding of and provides insight into the research problem (Creswell & Plano Clark, 2018).

Summary representative statements of two kinds were described to support findings in the integrated analysis: Those emphasized and/or repeated in association with the research questions, and those with compelling language or offering unique perspectives to the research questions. Finally, theme development described in the Phase II data analysis, was confirmed

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

during the integrated analysis via significant concepts linking the Phase I and Phase II data together.

Research Quality and Rigour

Quality and rigour were a priority in this study. Through mixing methods, the use of more than one source of data props the quality of this research (Lincoln & Guba, 1985). Creswell and Poth (2018) advise rigour has been a focus of concern in case study research, and is reliant on three factors: verification, validation and validity. Verification through, for example, literature searches and adhering to methods and keeping field notes, were critical to achieving research validity (Hesse-Biber & Johnson, 2015) and were important to this study.

Creswell and Plano Clark (2018) suggest specific validity threats in explanatory sequential mixed methods designs, which might include difficulty with connecting the initial Phase I results with the follow-up Phase II results. The validity of the research instruments and purposeful recruitment of science teachers with Grade 9 and/or Grade 10 teaching experience prior to and during the pandemic helped to support this connection and decrease this threat. A deductive approach to the development of the survey and interview protocol, from the relevant science education literature, Manitoba science curriculum documents, many years of experience I have teaching Grades 9 and 10 science, and my graduate work in science education helped to ground the validity of these research instruments.

Validity and reliability of the Phase I survey data were enhanced through careful design of the online survey research instrument connecting the demographic and research survey questions to the main research questions guiding this study (Toepoel, 2016). Guided by Sullivan and Artino's (2017) principles of survey design to utilize: technically accurate questions; simple, specific wording; complete sentences with as few words as possible; equal numbers of positive

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

and negative categories for scalar questions; both sides of behaviour scales in the question stem; and avoiding double-barrelled, leading and excessively long questions bolstered survey quality. I was directed by Vannette and Krosnick's (2018) content, cognitive, and usability standards to use a 5-point scale to optimize unipolar rating and maximize discrimination without sacrificing reliability, and to select verbal labels instead of numbers. Validity was further enhanced with the inclusion of several negatively-keyed questions, and an expected completion time of under 15 minutes to minimize survey-fatigue. I pretested the survey with three subjects similar to the target population to ensure question clarity prior to the start date. Finally, the survey data was reviewed for outliers, and for consistency, as varying degrees of frequency are expected (Sullivan & Artino, 2017).

Creswell and Poth's (2018) and Creswell and Plano Clark's (2018) strategies for validating qualitative research findings were an important guide for the Phase II interview data. Creswell and Plano Clark suggest that qualitative validity comes from standards based on researchers and participants, and overall trustworthiness or authenticity by assessing whether the information obtained through the qualitative data collection is accurate. Further rigour and validity were accomplished through various steps as Phase II of this study was conducted. First, to ensure interview accuracy, participants were provided a copy of the transcript data, with a request to check and respond within a two-week period. Second, analysis was conducted concurrently with data collection and I carefully coded the transcripts and carefully selected quotes of participant' experiences from the data. Finally, participants were provided with a one-page summary of results via email following the study's completion to ensure that participants were satisfied that they had expressed what they wanted to express in their interview, to support the validity of the Phase II results.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

To increase interpretive rigour in this study, I followed Teddlie and Tashakkori's (2009) recommendations to first pursue interpretive consistency by ensuring that my inferences followed relevant findings; and second, to attempt for theoretical consistency by ensuring my inferences were consistent with the current scholarly literature. Meta-inferences that I made during integration of the Phase I and Phase II data sets further strengthen rigour and trustworthiness of this study (Fetters et al., 2013). Additionally, trustworthiness of my interpretations was enhanced as I made some adjustments in response to numerous discussions with my advisor throughout the two-year data analysis period. Finally, I checked the Phase II and integrated findings against trustworthy criteria to guide qualitative research: credibility, dependability, confirmability and transferability (Creswell & Plano Clark, 2018; Lincoln & Guba, 1985). Lincoln and Guba indicate that detailed context and description of the case allow for comparisons that support transferability, and enhance trustworthiness of this research.

Mixed methods research scholars Hesse-Biber and Johnson (2015) claim "post-positivists strive for generalizability", but in case studies the aim is to often find transferability (p. 395). According to Eisenhart (2009) the tendency of inferences to extend beyond the participants and context is both possible and important in educational research. Fendler (2006) posits that generalization seeking to find an overall pattern from an array of specific examples can provide validation to those inferences, and Shavelson and Webb (2009) describe the value of generalizability for small cases studies. Moreover, generalization is important for educational researchers attempting to improve education, as otherwise, "it hardly seems likely that they would willingly devote their professional time and energy to studies that do not generalize in some way ... who really does not want to apply or infer from what has been learned in a study beyond the particular case?" (Eisenhart, 2009, p. 65). Generalizability however, was not a

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

primary goal of this study, yet the “snapshot” of experiences of Manitoba Grade 9 and Grade 10 science teachers throughout the COVID-19 pandemic and the research findings may be transferable to other similar situations.

Huberman and Miles (2002) posit thick descriptions of both the case study site and the site one wishes to generalize to, are vital for assessing the extent to which the findings from one study might occur in another situation. Maxwell (2022) explains that transferability as a strategy for generalization has been established in qualitative research and its use in mixed methods research depends on understanding how the meanings and processes might operate in a different context. Given the extremity of the unprecedented case study “site” of Manitoba Grade 9 and Grade 10 science classrooms during the COVID-19 pandemic, some of the findings of this study may be transferable to future extreme situations where remote teaching may be required; or across disciplines when practical learning opportunities are restricted. Maxwell (2022) emphasizes it is the responsibility of the researcher to provide sufficient contextual information to facilitate such a transfer, and contends the burden is on the reader or potential user of the results to determine how this information is relevant in a new context.

Chapter IV: Findings and Discussion

This chapter is organized to include: a discussion of the Phase I survey findings presented in tabular form and a summary of these findings; a discussion of the Phase II interview findings presented through the lens of seven themes and a summary of these findings; and an integrated analysis and discussion of the Phase I and Phase II findings. The main research question, and Phase I and Phase II sub-questions guiding this study are addressed in context with relevant findings.

Phase I: Survey Findings and Discussion

The Phase I data was collected from 58 Grade 9 and Grade 10 science teachers from urban and rural communities across Manitoba who responded to seven demographic questions and 30 research questions in the Phase I survey, between September 1, 2022 and October 21, 2022. Demographic data was collected through the first seven survey questions, to get a sense of the background and experiences of the respondents. These questions with teacher responses and associated descriptive statistics are presented in Table 2.

Table 2

Demographic Survey Questions 1 - 7

1. What is your science teaching experience?				
2 years or less	3 – 5 years	6 – 10 years	More than 10 years	
16%	10%	16%	58%	
2. Which best describes your subject expertise?				
Biology	Chemistry	Physics	General Science	Other
39%	8%	17%	23%	13%
3. Where do you currently teach Grade 9 and/or Grade 10 science?				
Urban Winnipeg	Urban other		Rural Manitoba	
58%	9%		33%	
4. Prior to the COVID-19 pandemic, how many times did you teach Grade 9 science in Manitoba?				
Never	1 – 2 times	3 – 5 times	More than 5 times	
26%	16%	11%	47%	
Mode		Mean		
More than 5 times		> 3 times		
5. How many times have you taught Grade 9 science during the COVID-19 pandemic?				
None	1 time	2 times	3 or more times	
30%	11%	20%	39%	
Mode		Mean		

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

3 or more times		2 - 3 times	
6. Prior to the COVID-19 pandemic, how many times did you teach Grade 10 science in Manitoba?			
Never	1 – 2 times	3 – 5 times	More than 5 times
24%	14%	9%	53%
Mode		Mean	
More than 5 times		> 3 times	
7. How many times have you taught Grade 10 science during the COVID-19 pandemic?			
None	1 time	2 times	3 or more times
26%	16%	14%	44%
Mode		Mean	
3 or more times		1 - 2 times	

The demographic information shared by the Phase I survey respondents was helpful to inform this study in three significant ways: First, teachers reported teaching in various school divisions including those in Winnipeg, other urban centers, and rural Manitoba, and possess diverse subject area expertise in the sciences. Second, most participants have considerable science teaching experience, with 58% reporting more than 10 years and 26% reporting five or fewer years. Third, close to half of the participants reported teaching Grade 9 and Grade 10 science more than five times prior to the pandemic (47% and 53%, respectively), and a significant proportion reported teaching Grade 9 and Grade 10 science three or more times during the pandemic (39% and 44%, respectively). Also important, Grade 9 and/or Grade 10 science teaching experience prior to and during the pandemic was required for participation in the survey as per the survey consent, however the data informs that 43 of 58 respondents taught science at both levels before the pandemic and 41 of 58 taught at both levels during the pandemic. Additionally, the diverse subject area expertise of respondents notably allows for a range of pedagogical perspectives across the multidisciplinary Grade 9 and Grade 10 science courses. With a large proportion of respondents reporting significant experience with teaching Grades 9 and 10 science both prior to and during the pandemic, greater familiarity with the associated Manitoba science curriculum documents might be logically expected and, as such, I see participant responses to the curriculum-based questions as providing valuable insights about

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the research questions. Analysis of the survey data against different demographic subgroups was not conducted, as similar responses were collected from participants in all subgroups.

Data collected from the 30 survey research questions informed the answers to the Phase I research questions, seeking to find out Grades 9 and 10 science teachers' curricular priorities and their pedagogical approaches, both prior to and during the pandemic. The first 20 and final six survey research questions have been grouped for analysis and discussion, given their focus, while findings from questions 21 through 24 are presented independently due to their distinct contributions to answering the Phase I research sub-questions.

Survey Questions 1 - 4

1. Prior to the pandemic, which best describes the clusters/units you taught in your Grade 9 science classes?
2. Since the pandemic began in March 2020, which best describes the clusters/units you taught in your Grade 9 science classes with school lockdowns and restrictions?
3. Prior to the pandemic, which best describes the clusters/units you taught in your Grade 10 science classes?
4. Since the pandemic began in March 2020, which best describes the clusters/units you taught in your Grade 10 science classes with school lockdowns and restrictions?

Table 3

Survey Questions 1 – 4 Responses

Clusters/Units Taught in Grade 9 Science	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Taught all or most of the learning outcomes (LO) in all 4 clusters	54	18	-36%
Taught some of the LO in all 4 clusters	14	21	+7%
Taught all or most of the LO in 3 clusters	32	46	+14%
Taught some of the LO in 3 clusters or less	0	15	+15%
Clusters/Units Taught in Grade 10 Science			

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Taught all or most of the learning outcomes (LO) in all 4 clusters	42	8	-34%
Taught some of the LO in all 4 clusters	8	19	+11%
Taught all or most of the LO in 3 clusters	47	52	+5%
Taught some of the LO in 3 clusters or less	3	21	+18%

These questions were positioned at the start of the survey for teachers to assess their curricular priorities of the four clusters (units) in Grade 9 and/or Grade 10 science prior to and during the pandemic, before any consideration of their teaching approaches. As previously described, three of the four clusters in each grade are rooted in the foundational disciplines of biology, chemistry and physics to prepare students for future courses in school sciences, with a fourth cluster representing a different and diverse topical science, and interdisciplinary learning outcomes. From the pre-pandemic data collected in these questions, parallel findings in Grade 9 and Grade 10 science were identified with three similarities. First, only about half of respondents (54% in Grade 9; 42% in Grade 10), reported teaching “all or most of the learning outcomes (LOs) prescribed in the four clusters” of the Manitoba science curriculum, while another significant proportion reported teaching “all or most of the LOs in three clusters” (32% in Grade 9; 47% in Grade 10). Considering all four clusters and the entirety of LOs in Grade 9 and 10 science are mandated in the Manitoba Science curriculum documents; it was surprising to me that many teachers reported only teaching most LOs in three clusters. This was further investigated in the Phase II interviews. Second, as only a small proportion of teachers reported teaching some of the LOs from three or four clusters (14% in Grade 9; 11% in Grade 10 respectively), it seems that prior to the pandemic, most teachers (86% in Grade 9; 89% in Grade 10) taught either three or four units and their associated LOs thoroughly. Finally, it was noted that very few respondents reported teaching only “some of the LOs in three clusters or less” prior to the pandemic (0% in Grade 9; 3% in Grade 10). This was not surprising to me given my

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

experience teaching Grade 9 and Grade 10 science in Manitoba high schools which led me to assume that science teachers focus greatly on teaching the disciplines of biology, chemistry and physics, and preparing their students for the next levels in high school science. Overall, the data in questions 1-4 suggests that a large proportion of Manitoba Grade 9 and Grade 10 science teachers (46% and 58%, respectively) were unable to teach the entirety of the curricular LOs prior to the pandemic.

Of additional significance to this study, the survey data from questions 1-4 showed a shift in the number of clusters and proportion of LOs taught during the pandemic, with overall fewer clusters and LOs reportedly taught in each grade. Most prominent was a decline in the proportion of teachers who reported teaching “all or most of the LOs in all four clusters” (36% fewer in Grade 9; 34% fewer in Grade 10). From my perspective, a surprising proportion of teachers, indicated they still taught “all or most of the LOs in all four clusters” (18% in Grade 9; 8% in Grade 10) during the pandemic, despite multiple lockdowns, altered modes of instruction and restrictions to practical learning. How some teachers were able to accomplish this was of interest to me and I investigated it further in the Phase II interviews. The data additionally revealed a positive shift in respondents teaching all four, to only three clusters during the pandemic (14% in Grade 9; 5% in Grade 10). Another important shift was identified as an increase in the proportion of teachers who reported teaching “some of the LOs in three clusters or less” during the pandemic (from 0% to 15% in Grade 9; from 3% to 21% in Grade 10). From this data, it seems evident that some Manitoba Grade 9 and Grade 10 teachers were unable to teach the entirety of three clusters during the pandemic and that this may have consequences for student learning including important pre-requisite knowledge for further science education.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

As thoroughly described in the literature and evident in the responses to survey questions 1-4, the sudden shift to different instructional modes required teachers to rapidly adjust what they taught during the pandemic. Important questions remain: Why did teachers choose to teach fewer clusters and which ones were prioritized or abandoned? And what impacts did these decisions have for students learning science?

Due to the congruent nature of survey questions 5-8 and 9-12, they have been grouped for analysis and discussion.

Survey Questions 5 – 6

5. Prior to the pandemic, what cluster/unit did you prioritize or spend the most time teaching in your Grade 9 science classes?
6. Since the pandemic began in March 2020, what cluster/unit in your Grade 9 science classes have you prioritized or spent the most time teaching?

Table 4

Survey Questions 5 – 6 Responses

Grade 9 clusters prioritized	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Reproduction	36	33	-3%
Atoms and Elements	61	64	+3%
Nature of Electricity	3	3	-
Exploring the Universe	0	0	-

Survey Questions 7 - 8

7. Prior to the pandemic, what cluster/unit did you give less priority to, or spend the least time teaching in your Grade 9 science classes?
8. Since the pandemic began in March 2020, what cluster/unit in your Grade 9 science classes have you given less priority to or spent the least time teaching?

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Table 5*Survey Questions 7 – 8 Responses*

Grade 9 clusters given less priority/time	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Reproduction	0	0	-
Atoms and Elements	0	0	-
Nature of Electricity	9	27	+18%
Exploring the Universe	91	73	-18%

The data provided by participating Grade 9 science teachers in questions 5-8 was critical to establish what might be considered usual or normal curricular cluster priorities for these teachers, and to reveal the shift in these priorities during the pandemic. The Grade 9 chemistry cluster, Atoms and Elements, is essential for prerequisite knowledge, skills and attitudes required in the Grade 10 science chemistry cluster. It was not a surprise to me that 61% of participating Grade 9 teachers prioritized and/or spent the most time teaching this unit prior to the pandemic and 64% continued to prioritize teaching chemistry during the pandemic. The Reproduction biology unit (cluster 1 in Grade 9) was the second most prioritized cluster, with 36% of teachers pre-pandemic and 33% during the pandemic prioritizing the teaching of this unit. Thus, these two clusters combined (i.e., Atoms and Elements, and Reproduction) were prioritized both pre- and during the pandemic by 97% of the participating Grade 9 teachers.

In keeping with those results, as shown in Table 5, participating Grade 9 teachers ranked Exploring the Universe as the cluster of lowest priority: 91% did not prioritize it prior to the pandemic, and 73% continued to position it as the lowest priority during the pandemic, a decrease of 18%. Interestingly, 18% also indicate the shift in priority of the Nature of Electricity cluster in Grade 9 science, as the second lowest prioritized unit pre- and during the pandemic,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

however with a sizable difference in priority ranking when compared to the lowest prioritized unit.

Similarly, data collected from Grade 10 science teachers in Questions 9-12 provided evidence of which units were prioritized before and during the pandemic, as presented in Tables 6 and 7.

Survey Questions 9 - 10

9. Prior to the pandemic, what cluster/unit did you prioritize or spend the most time teaching in your Grade 10 science classes?
10. Since the pandemic began in March 2020, what cluster/unit in your Grade 10 science classes have you prioritized or spent the most time teaching?

Table 6*Survey Questions 9 – 10 Responses*

Grade 10 clusters prioritized	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Dynamics of Ecosystems	12	13	+1%
Chemistry in Action	70	70	-
In Motion	18	17	-1%
Weather Dynamics	0	0	-

Survey Questions 11 - 12

11. Prior to the pandemic, what cluster/unit did you give less priority to or spend the least time teaching in your Grade 10 science classes?
12. Since the pandemic began in March 2020, what cluster/unit in your Grade 10 science classes have you given less priority to or spent the least time teaching?

Table 7*Survey Questions 11 – 12 Responses*

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Grade 10 clusters given less priority/time	Teacher Response (%)		Change
	Pre-pandemic	During pandemic	
Dynamics of Ecosystems	9	8	-1%
Chemistry in Action	2	3	+1%
In Motion	0	3	+3%
Weather Dynamics	89	86	-3%

The data collected from participating Grade 10 science teachers in Questions 9-12 was key to establishing their usual curricular cluster priorities prior to the pandemic, and to reveal any shift in these priorities during the pandemic. From the data, it was interesting to note that the majority of Grade 10 science teachers remained steadfast in their priorities, despite the arrival of the COVID-19 pandemic and the disruptions to their teaching practice, as was also seen with the responses of the Grade 9 teachers. Extreme differences in cluster precedence were found as 70% of Grade 10 teachers prioritized the Chemistry in Action cluster while none prioritized Weather Dynamics—prior to or during the pandemic, revealing the significance of teaching chemistry in this grade and insignificance of the weather unit for these teachers. Teacher priorities regarding the other two clusters also persisted throughout the pandemic, with 18% prioritizing the In Motion physics unit prior to and 17% during the pandemic; and 12% prioritizing the Dynamics of Ecosystems biology unit prior to and 13% during. Notably, although fewer of these teachers top rank these units, they are the most important to some. Very few respondents considered the chemistry and the physics units to be low priority, showing importance for teaching the scientific concepts, skills and attitudes in these units. It seems likely to me that since some science teachers also teach chemistry, physics and/or biology at the next and higher levels, they are aware of prerequisite learning outcomes students must achieve for success in their subsequent courses and this may be part of their rationale for prioritizing these units. Standing out, a large proportion of respondents (70%) prioritized the chemistry unit over the other 3 units in Grade 10 science, both

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

before and during the pandemic; while strikingly, close to 90% of respondents gave lowest priority to teaching the weather unit, both prior to and during the pandemic while 0% ranked this unit a priority. These survey findings led me to think about two important questions for analysis of the Phase II interviews: What reasons underpinned this compelling position of Grade 10 teachers, and what are the potential impacts for Manitoba Grade 10 students who take this course?

Overall, the Phase I survey data regarding Grade 9 and Grade 10 curricular priorities reveal that chemistry units and their LOs are of notably highest priority for teachers in both grades, and the clusters and LOs of significantly lowest priority in both grades are the final units in each curriculum: Exploring the Universe in Grade 9 science and Weather Dynamics in Grade 10 science. Further understandings of what teachers chose to teach or not teach in Grade 9 and Grade 10 science prior to and during the pandemic are expanded on in the Phase II interviews analysis and discussion. In summary, teacher content priorities identified from the Grades 9 and 10 science teacher responses in Questions 5-12 helped to answer the first Phase I research question, and additionally set the stage for the Phase II interviews to investigate how such adjustments may have impacted teachers' potential to effectively teach the LOs in these courses, and to advance student scientific literacy.

Questions 13 through 20 centered on curricular focus in Grades 9 and 10 science (i.e., inquiry, debate of scientific issues, and technological design) and the teaching of mandated learning outcomes (general learning outcomes, specific learning outcomes, and Cluster 0 specific learning outcomes). Guided by recommended practices in survey construction described by Vannette and Krosnick (2018), a five-point scale was selected for these questions to maximize discrimination without sacrificing reliability.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Participants were deliberately asked the next two questions (13-14) prior to and separate from subsequent questions about curricular LOs to gather data on important pedagogical approaches known to foster scientific literacy, as previously described in the science education literature and as outlined in the Grade 9 and 10 science curriculum standards documents. Understanding that Manitoba's Five Foundations for Scientific Literacy are foundational to promoting pedagogy linked with SI, debate and the design process, I felt that asking teachers important questions about such practices was important.

Survey Questions 13 – 14

13. Prior to the pandemic, how often would you engage your Grade 9 or Grade 10 science students in scientific inquiry, debate about scientific issues and/or the design process to solve a technological problem?
14. During the pandemic, how often have you engaged your Grade 9 or Grade 10 science students in scientific inquiry, debate about scientific issues and/or the design process to solve a technological problem?

Table 8

Survey Questions 13 – 14 Responses

Frequency engaging grades 9 and 10 students in SI, debate about scientific issues, or design process to solve a technological problem	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Not at all (1)	11	14	+3%
Not often (2)	6	28	+22%
Occasionally (3)	48	40	-8%
Often (4)	23	12	-11%
Consistently (5)	12	6	-6%
Mode	3	3	
Mean	3.17	2.68	

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

To teach scientific and technological concepts, skills and attitudes and to foster scientific literacy, there is widespread agreement that teachers must regularly engage their students in learning opportunities including SI, debate and the design process (e.g., Beauchamp et al., 2021; Crujeiras-Pérez & Jiménez-Aleixandre, 2017; Duran et al., 2016). Moreover, the previously described Manitoba Senior Years Science curriculum indicates concrete and contextual learning activities that include scientific inquiry, technological problem solving (the design process) and decision-making support the development of functional scientific literacy in all students (MET, 2000). Consequently, I expected that teachers' responses would indicate such practice; indeed, 83% of teachers reported engaging students in SI, debate and the design process to solve a technological problem prior to the pandemic (35% often or consistently; 48% occasionally). However, 17% of respondents indicated they did not engage students in such learning activities often or even at all prior to the pandemic; while during the pandemic, this percentage increased to 42%. How teachers were able to cultivate learning environments conducive to advancing scientific literacy skills and attitudes without such student opportunities emerged as an important question from these findings. Further, during the pandemic, 58% of teachers indicated engaging students in these important pedagogical approaches that are advantageous to student development of scientific literacy "occasionally", "often" or "consistently". How they accomplished this given the teaching and learning constraints during the pandemic was a topic of discussion in the Phase II interviews.

The next six questions (15-20) were designed to identify teaching priorities associated with the scientific and technological concepts, skills and attitudes in the curricular general learning outcomes (GLOs), specific learning outcomes (SLOs) and Cluster 0 Overall Skills and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Attitudes SLOs prior to and during the pandemic. These are presented separately for discussion given the distinct influence of each dimension within a teacher's pedagogical approach.

Survey Questions 15 – 16

15. Prior to the pandemic, how focused/centered were you on teaching the general learning outcomes (GLOs) described in Manitoba's Five Foundations for Scientific Literacy: Nature of Science (NOS); Science, Technology, Society and Environment (STSE); Scientific and Technological Skills and Attitudes; Essential Scientific Knowledge and Unifying Concepts?

16. During the pandemic, how focused/centered are you on teaching the general learning outcomes (GLOs) described in Manitoba's Five Foundations for Scientific Literacy?

To preface the analysis of these questions, it has become markedly evident to me in my experience as a Grade 9 and Grade 10 science teacher and more recent experience advising and teaching pre-service teachers that many science teachers are unaware of the substance of the GLOs. Moreover, many seem to be unaware of their application to practice, despite the foundational nature of these learning outcomes for scientific literacy and their fundamental position in the high school science curricula (MET, 2000; MEY, 2003). Throughout my science teaching career, foundational GLOs were oddly never discussed with science colleagues, department heads, administrators, or mentioned in broader science education professional development dialogue, so they seem to be of questionable importance to some or perhaps many science educators.

Table 9

Survey Questions 15 – 16 Responses

Teacher Response (%)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

How focused/centered are you on teaching the GLOs?	Pre-pandemic	During pandemic	Change
Extremely (1)	12	4	-4%
Very (2)	29	12	-17%
Somewhat (3)	33	43	+10%
Not so much (4)	16	33	+17%
Not at all (5)	10	8	-2%
Mode	3	3	
Mean	2.82	3.29	

Pre-pandemic data from the group of responding teachers reflect a fairly broad distribution of responses, with the largest proportion of teachers indicating they were “somewhat focused” on teaching the GLOs: 33% prior to and 43% during the pandemic. Most notably from this data, the group of teachers expressing greater focus on teaching the GLOs prior to the pandemic (“extremely” or “very” focused) declined from 41% to 16% during the pandemic; while the group of teachers indicating GLOs were “not at all” or “not so much” a focus, increased from 26% to 41%. These results reveal a marked shift to a decreased focus on teaching the curricular GLOs during the pandemic. The implications of this for student scientific literacy may be considerable, since a lack of focus on these foundational GLOs may limit effective science pedagogy for scientific literacy and, correspondingly, reduce students’ opportunity to learn essential scientific and technological knowledge, skills and attitudes, and about the nature of science itself. Why some Manitoba Grades 9 and 10 science teachers reduced their focus on teaching these critical GLOs was discussed during the Phase II interviews, along with where they shifted their focus.

Participant responses to the next question were helpful at this point in data collection, allowing for the primary focus of Grades 9 and 10 science teachers to emerge within the context of their perspective on GLOs.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Survey Questions 17 – 18

17. Prior to the pandemic, how focused/centered were you on teaching the specific or prescribed learning outcomes (SLOs) described in the Manitoba science curriculum documents?
18. During the pandemic, how focused/centered are you on teaching the specific or prescribed learning outcomes (SLOs) described in the Manitoba science curriculum documents?

Table 10*Survey Questions 17 – 18 Responses*

How focused/centered are you on teaching the SLOs?	Teacher Response (%)		Change
	Pre-pandemic	During pandemic	
Not at all (1)	4	4	-
Not so much (2)	2	6	+4%
Somewhat (3)	12	34	+22%
Very (4)	55	46	-9%
Extremely (5)	27	10	-17%
Mode	4	4	
Mean	4.00	3.52	

Rather expectedly, a total of 82% of Grade 9 and Grade 10 science teachers reported being “very” (55%) or “extremely” (27%) focused on teaching the SLOs in the Manitoba science curriculum documents (MET, 2000; MEY, 2003) before the pandemic. During the pandemic, a general shift to a reduced priority on SLOs is revealed in the data. A decrease in focus on SLOs during the pandemic was substantiated by 17% fewer teachers being “extremely” focused on teaching SLOs and 22% more respondents being “somewhat” focused on the SLOs during the pandemic. With Grades 9 and 10 science teaching experience both prior to and during the pandemic, I understand the challenges associated with teaching the lengthy list of unit-specific SLOs in the combined four clusters in each course first-hand, as well as the professional

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

expectations teachers hold of themselves to provide students with opportunity to learn all of the SLOs in these courses. And although contrary to their reported perspective on GLOs, in my experience working with many colleagues I believe Grade 9 and Grade 10 science teachers are largely focused on teaching the SLOs in their courses, and are often centered on covering large volumes of conceptual material given the lengthy list within the four clusters of these general science courses—67 in Grade 9; and 43 in Grade 10.

Further discussions with participants regarding their focus on SLOs in the Phase II interviews allowed individual perspectives regarding changes in focus on teaching all learning outcomes during the pandemic to emerge.

Survey Questions 19 – 20

19. Prior to the pandemic, how focused/centered were you on teaching the Overall Skills and Attitudes learning outcomes described in Cluster 0 of the Manitoba science curriculum documents?

20. During the pandemic, how focused/centered are you on teaching the Overall Skills and Attitudes learning outcomes described in Cluster 0 of the Manitoba science curriculum documents?

Table 11*Survey Questions 19 – 20 Responses*

How focused/centered are you on teaching the Cluster 0 Overall Skills and Attitudes:	Teacher Response (%)		
	Pre-pandemic	During pandemic	Change
Not at all (1)	4	6	+2%
Not so much (2)	16	28	+12%
Somewhat (3)	35	36	+1%
Very (4)	25	26	+1%
Extremely (5)	20	4	-16%
Mode	3	3	
Mean	3.41	2.94	

Fostering scientific literacy in Grade 9 and Grade 10 science requires a focus on teaching the Cluster 0 Skills and Attitudes SLOs. The data collected here revealed an average response from teachers that they were “somewhat focused” on teaching the Cluster 0 SLOs both prior to and during the pandemic. As Toepoel (2017) suggests, survey participants might select a “more middle option”, particularly when responding to questions that are more difficult to process (p. 35). Yet, rather than being considered unreliable, I found value in this average neutral response—without a robust focus on teaching the Cluster 0 SLOs, teachers bring reduced capacity to teach skills and attitudes required to advance scientific literacy.

The Skills and Attitudes SLOs required for developing scientific literacy are labelled “Cluster 0” (MET, 2000, pp. 3.10-3.14) in the Grade 9 and Grade 10 science curriculum documents, despite prefacing the other SLOs in these documents. First, it could be argued that being labelled as cluster “zero” fails to inspire importance; and second, these SLOs occupy a mere few pages labelled 0.1 to 0.6 in the Grade 9 curriculum (MET, 2000) and 0.1 to 0.8 in the Grade 10 curriculum (MEY, 2003); while the vast bulk of each document is devoted to the SLOs in clusters 1-4, mostly focused on content. Additionally, these unit-specific, content focused SLOs are positioned at the start of each respective cluster in larger font, giving the apparent message to science educators that conceptual knowledge SLOs take greater priority over the Cluster 0 Skills and Attitudes SLOs.

Further significance to student development of scientific literacy accompanies an identifiable shift in responses to these questions before and during the pandemic, as 16% fewer teachers reported being “extremely” focused on teaching these skills and attitudes SLOs during the pandemic, while 12% more respondents said they were “not so much” focused on teaching

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

these SLOs during the pandemic. Overall, the mean response of these teachers indicates a general shift from being more than “somewhat” focused on teaching the Cluster 0 SLOs prior to the pandemic, to being slightly less than “somewhat” focused on them during the pandemic—and of importance for the Phase II discussions with participants.

The data collected in these three pairs of questions (15-16; 17-18; 19-20) regarding participants' focus on teaching the mandated learning outcomes in the curriculum documents were also discussed in Phase II interviews to seek understanding of the priorities expressed in teaching GLOs, SLOs and Cluster 0 SLOs prior to and during the pandemic, in addition to gathering further insights into teachers' LO priorities for teaching Grades 9 and 10 science. Of particular interest was the trend identified in these three pairs of questions, that teachers reported an overall reduced focus on teaching the GLOs, SLOs and the Cluster 0 SLOs, soliciting the question, what did their focus shift to? Important insights to help understand this shifted focus were gleaned from the Phase II interviews.

The survey Questions 21 through 24 were designed to address the second Phase I research question concerning LOs taught through practical work prior to the pandemic, and those taught through alternate activities amid pandemic lockdowns and restrictions.

Survey Question 21

21. In general, how important are practical learning opportunities for your Grade 9 and/or Grade 10 students to develop scientific literacy—concepts, skills and attitudes?

Table 12***Survey Question 21 Responses***

In general, how important are practical learning opportunities for your Grade 9 and/or Grade 10 students to develop scientific literacy concepts, skills and attitudes?	
	Teacher Response (%)
Not at all important (1)	0 %

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Not so important (2)	0 %	
Somewhat important (3)	17 %	
Very (4)	42 %	
Extremely (5)	41 %	
	Mode	Mean
	4	4.23

Scholarship in science education has indicated that practical learning opportunities are necessary to learn about the processes of science and are critical for learning concepts, skills and attitudes to develop scientific literacy (Chadwick & McLoughlin, 2021; Kelley, 2020; Rossetini et al., 2021), and that without practical work, LOs are compromised in all science education disciplines (Gya & Bjune, 2021). Effectively promoting scientific literacy requires teachers to regularly engage students in kinesthetic activities (MEY, 2003), a curricular emphasis corroborated by the participating teachers' responses: the large majority (83%) of teachers believe practical learning opportunities are "very" or "extremely" important, while 17% believe they are "somewhat important". Aligning with the scholarly literature on best practices in science education, the general perspective of Manitoba Grades 9 and 10 science teachers who participated in this survey suggests effective pedagogy to promote scientific literacy requires students to regularly engage in practical learning. How often teachers could provide practical learning opportunities through the pandemic lockdowns and restrictions was explored in the next question.

Survey Question 22

22. During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to experiment, use data collection tools, make measurements, control variables, and/or use WHMIS regulations and safety equipment in your classes?

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Table 13*Survey Question 22 Responses*

During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to experiment, use data collection tools, make measurements, control variables, and/or use WHMIS regulations and safety equipment in your classes?	
	Teacher Response (%)
Not at all (1)	18 %
Maybe once or twice (2)	42 %
Often, but less than before the pandemic (3)	38 %
Just as frequently as before (4)	2 %
More frequently than before the pandemic (5)	0 %
	Mode
	2
	Mean
	2.24

While a large proportion of the participant teachers (82%) indicated their students had some opportunity to engage in data collection and/or apply safe laboratory practices and use safety equipment during the pandemic lockdowns and restrictions, only 2% indicated such opportunity occurred just as frequently before the pandemic. Although to what extent these opportunities were curtailed during the pandemic cannot be determined, 38% of respondents indicated that their students were exposed to laboratory and experimental practical activities “often, but less than before the pandemic”. This indicates that some Grade 9 and Grade 10 Manitoba students had less opportunity to do practical work during the pandemic. As a significant number of LOs in the Grade 9 and Grade 10 science curriculum require students to experiment, use data collection tools, make measurements, control variables, and/or use WHMIS regulations and safety equipment, exploring this reduced opportunity was important for the Phase II discussions with teachers.

The implications of these limitations on practical work to learn science throughout this period extend beyond restrictions to the practical activities themselves, and into the potential loss

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

of opportunities for students to collaborate and work cooperatively to advance functional scientific literacy competencies, as indicated in the responses to the next question.

Survey Question 23

23. During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to work cooperatively with group members to plan an experiment, carry out the plan, and troubleshoot problems if they arise?

Table 14*Survey Question 23 Responses*

During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to work cooperatively with group members to plan an experiment, carry out the plan, and troubleshoot problems if they arise?	
	Teacher Response (%)
More frequently than before the pandemic (1)	0 %
Just as frequently as before (2)	4 %
Often, but less than before the pandemic (3)	20 %
Not often, maybe once or twice (4)	56 %
Not at all (5)	20 %
	Mode
	4
	Mean
	3.92

Aligning with teacher responses in the previous question, a reduction in student opportunity to experiment during the pandemic meant a reduction in opportunity to collaborate, cooperate, troubleshoot and learn with classmates while navigating experimental processes. 20% of teachers reported their students had such opportunities “often, but less than before the pandemic”. In light of the scholarly perspective that remote or virtual opportunities such as break-out rooms within digital platforms are not as effective as in-class collaborative opportunities (Garcia-Vedrenne et al., 2020; Lynn et al., 2020), it becomes important to ascertain the types of experiments and collaborative opportunities students were afforded during the pandemic, which is explored further in the Phase II interviews.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The collective data from Questions 21-23 were helpful to determine participating science teachers' perspectives of three key elements contributing to the main research question guiding this study: First, the importance they attributed to practical work to the development of scientific literacy; Second, the frequency of student opportunity to practice scientific procedures during the pandemic; Third, the frequency of student opportunity for authentic investigative experiences important for the development of scientific literacy. As Hodson (1993) pointed out and as described in Chapter 2, in order to learn science, students require procedural knowledge, investigative expertise, and conceptual understanding; but as the Manitoba science curriculum standards indicate, they also require opportunities to work cooperatively with other students (MET, 2000). It was determined from the combined survey data in Questions 21-23 that teachers agree practical experiences are necessary to learn science, however opportunities to develop procedural knowledge or investigative expertise or to learn in collaboration with other students were significantly restricted during the pandemic. The next question was a direct attempt to seek teachers' perspectives on their ability to foster scientific literacy during the pandemic, while students were restricted from directly "experiencing" science.

Survey Question 24

24. How confident have you been in your ability to foster scientific literacy—concepts, skills and attitudes in Grade 9 and/or Grade 10 science throughout the COVID-19 pandemic?

Table 15***Survey Question 24 Responses***

How confident have you been in your ability to foster scientific literacy—concepts, skills and attitudes in Grade 9 and/or Grade 10 science throughout the COVID-19 pandemic?	
	Teacher Response (%)
Extremely confident (1)	2 %
Very confident (2)	22 %
Somewhat confident (3)	54 %

Not very confident (4)	16 %
Not confident at all (5)	6 %
	Mode
	3
	Mean
	3.02

In response to this question, 24% of the teachers collectively expressed significant confidence in fostering scientific literacy throughout the pandemic, while almost the same number (22%) expressed a lack of confidence in their ability to do so. I expected the range of teacher responses to strongly lean toward ‘not confident’ given the rapid switch to online instruction and the lack of training and resources to support teachers as they made this change. Responses to this question reveal a clear picture of uncertain confidence in the ability of Grades 9 and 10 teachers to foster scientific literacy during the pandemic and are of central importance to the main research question. Yet, from the standpoint that 78% of the teachers overall, expressed some degree of confidence in their ability to foster scientific literacy competencies during the pandemic while practical work was restricted, understanding how they were able to do so was a heightened objective as I analysed the Phase II interviews. Further data regarding teachers’ perceived ability to adequately explore skills and attitudes SLOs most closely associated with developing scientific literacy was collected in the next two questions.

Survey Questions 25 – 26

25. Prior to the COVID-19 pandemic, which of the following skills and attitudes specific learning outcomes did you adequately explore with your students in your Grade 9 and/or Grade 10 classes (select all that apply).
26. Since the start of the COVID-19 pandemic in March 2020, which of the following skills and attitudes specific learning outcomes have you adequately explored with lockdowns and/or restrictions in your Grade 9 and/or Grade 10 classes? (Select all that apply).

Table 16

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Survey Questions 25 – 26 Responses

Skills and Attitudes specific learning outcomes (SLOs) adequately explored with Grade 9 and/or Grade 10 students prior to the COVID-19 pandemic and during the pandemic with lockdowns and/or restrictions	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
Propose questions to be tested experimentally	70	38	-32
Identify stakeholders and initiate research related to a scientific issue	48	29	-19
Select, integrate, summarize and evaluate information	87	76	-11
Identify mathematical relationships between variables	85	80	-5
Plan an experiment to answer a specific scientific question	56	33	-23
Carry out procedures to control variables and repeat experiments for increased accuracy and reliability	59	31	-28
Understand WHMIS/MSDS, and demonstrate work habits that ensure safety for self/others with consideration for the environment	80	56	-24
Work cooperatively with group members to carry out a plan and troubleshoot problems as they arise	85	49	-36
Select and use appropriate methods and tools for measuring and collecting data	78	42	-36
Record, organize and display data to look for trends and discrepancies	80	76	-4
Discuss science and technology, and appreciate and respect cultural contributions throughout history	65	69	+4
Discuss social, economic, and environmental effects of past and present scientific and technological endeavors	70	76	+6
Demonstrate interest and personal involvement in STSE (science, technology, society and environment) issues, and relate personal activities and career choices to scientific disciplines	65	56	-9
Demonstrate confidence in ability to carry out scientific investigations and address STSE issues	54	24	-30
Value skepticism, honesty, accuracy, precision, perseverance, and open-mindedness, and be sensitive and responsible to human needs and a sustainable environment	78	80	+2

As previously noted, these questions were deliberately positioned later in the survey, to separate them from earlier questions (19-20) focused on Cluster 0 Skills and Attitudes SLOs; and were designed to draw participant' attention to 15 of 48 Skills and Attitudes SLOs in Grades 9 and 10 science vital for the development of student scientific literacy. These were specifically selected to represent a wide range of skills and attitudes without mention of "Cluster 0"; to limit categorization so teachers would focus their responses to these SLOs in their teaching.

Overall, results revealed that prior to the pandemic, a large proportion of teachers perceived they were adequately able to explore these skills and attitudes SLOs with their science

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

students. Yet, if 56% of teachers did not adequately explore “Plan an experiment to answer a specific scientific question” before the pandemic, how they were able to advance student scientific investigative knowledge that Hodson (1933) indicated essential for learning science, was an important question for the Phase II discussions. During the pandemic, an overall decline in teachers’ perceived adequacy to explore most of the scientific and technological skills and attitudes SLOs is evident in the data, with the most significant declines in “Work cooperatively with group members to carry out a plan and troubleshoot problems as they arise” and “Select and use appropriate methods and tools for measuring and collecting data”. More than a quarter of the respondents also reported declines in other SLOs most closely associated with practical learning activities, such as “Carry out procedures to control variables and repeat experiments for increased accuracy and reliability”, and “Demonstrate confidence in ability to carry out scientific investigations and address STSE issues”—which was unsurprising with pandemic restrictions of practical work.

The teacher responses to these questions generally fell into two groups: those linked to Cluster 0 SLOs associated with learning science skills; and those linked more closely with learning science attitudes. Evident in the collective data resulting from these questions, teacher capacity to adequately explore SLOs for learning scientific procedural skills was significantly reduced during the pandemic; while teacher capacity to adequately explore SLOs fostering attitudes was less impacted, or even improved marginally in some instances. For example, while 70% of teachers reported being adequately able to explore the SLO “Discuss social, economic, and environmental effects of past and present scientific and technological endeavors” prior to the pandemic, 76% were able to do so during the pandemic. Whether teachers were afforded increased opportunity to explore this SLO during the pandemic as the result of lost opportunity

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

to explore other SLOs requiring practical work, what types of learning activities teachers implemented, and how they adjusted to adequately explore some of the Cluster 0 Overall Skills and Attitudes SLOs during the pandemic, were important questions explored during the Phase II interviews.

To answer the second Phase I research question, an investigation of Grade 9 and Grade 10 cluster-specific SLOs taught through practical work prior to the pandemic, and those taught through alternative activities during the pandemic were the focus of the final two pairs of survey questions.

Survey Questions 27 – 28

27. Prior to the COVID-19 pandemic, which of the following specific learning outcomes

(SLOs) did you teach through “hands-on” learning activities/practical work in your Grade 9 science classes? (Select all that apply if you taught Grade 9 science)

28. Since the start of the pandemic in March 2020, which of the following specific Grade 9

learning outcomes (SLOs) did/do you teach using different/alternative learning activities not “hands-on”/don’t involve practical work? (Select all that apply if you taught Grade 9 science)

Table 17***Survey Questions 27 – 28 Responses***

Grade 9 specific learning outcomes (SLOs) that were taught through “hands-on” learning activities/practical work prior to the COVID-19 pandemic, and through alternative learning activities since the start of the pandemic that were not hands-on/did not involve practical work:			
	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
Reproduction:			
Illustrate and explain the process of mitotic cell division in plants and animals	97	88	-9
Investigate and describe agricultural applications of asexual reproduction	55	61	+6
Compare and contrast the function of mitosis to meiosis	82	85	+3

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Investigate and explain adaptations of plant and animal species which enhance reproductive success	58	65	+7
Observe, collect and analyze class data of single trait inheritance	85	50	-35
Use a pedigree to track the inheritance of a single trait	39	38	-1
Investigate environmental factors and personal choices that may lead to genetic mutations	39	73	+34
Discuss current and potential applications and implications of biotechnologies including genetic engineering/screening, cloning and DNA fingerprinting	64	65	+1
Teacher Response (%) Pre- During Pandemic Pandemic Change			
Atoms and Elements:			
Assemble or draw Bohr atomic models for the first 18 elements	94	78	-16
Investigate the development of the periodic table as a method of organizing elements	64	74	+10
Investigate the characteristic properties of metals, non-metals and metalloids like ductility, lustre and reactivity, and classify elements according to these properties	91	67	-24
Relate the reactivity and stability of different families of elements to their atomic structure	85	81	-4
Investigate properties of substances like durability, usefulness and safety, and explain the importance of knowing these properties	64	56	-8
Differentiate between physical and chemical changes	97	81	-16
Experiment to determine indicators of chemical change	94	56	-38
Investigate technologies and natural phenomena that demonstrate chemical change in everyday situations	64	48	-16
Teacher Response (%) Pre- During Pandemic Pandemic Change			
Nature of Electricity:			
Demonstrate evidence for the existence of two types of charge	81	56	-25
Explain how a discrepant event can be used to evaluate the particle model of electricity	50	32	-18
Investigate and explain electrostatic phenomena like conduction, induction and grounding using the particle model of electricity	81	68	-13
Investigate common electrostatic technologies and phenomena like photocopying and electrostatic spray-painting and safety measures like static straps	47	24	-23
Construct one or more electrostatic apparatus like a pie-plate electrophorus, and explain how they function	78	28	-50
Demonstrate and explain the like nature of electrostatics and current electricity including discharging an electrophorus through a neon bulb	50	20	-30
Construct electric circuits in series and parallel using schematic diagrams	97	60	-37
Use appropriate instruments and units to measure voltage, current and resistance	75	56	-19
Compare and contrast voltage and current in series and parallel circuits, including cells and resistance	78	68	-10
Investigate and describe qualitatively the relationship among current, voltage and resistance in a simple circuit	78	60	-18
Relate the energy dissipated in a circuit to the resistance, current and brightness of bulbs	66	36	-30
Explain the parallel circuits, components including switches, fuses, outlets and circuit breakers, and the safety aspects of household wiring	69	56	-13

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Analyze the electrical energy consumption of a household appliance, including EnerGuide consumption and reading hydro meters	53	44	-9
	Teacher Response (%)		
	<u>Pre-Pandemic</u>	<u>During Pandemic</u>	<u>Change</u>
Exploring the Universe:			
Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects with altitude and azimuth	62	38	-24
Observe the motion of visible celestial objects and organize collected data, such as tracking the position of the moon/planets over time or sunrise/sunset data	41	24	-17
Explain the apparent motion of the Sun, stars, planets, and the Moon as seen from Earth including daily rising/setting, seasonal constellations and retrograde motion	79	57	-22

From the responses provided by Grade 9 science teachers in these two questions (27-28), it is evident that prior to the pandemic a large proportion of teachers taught numerous SLOs through practical work, and during the pandemic a smaller percentage reported teaching these SLOs through alternative learning activities not practical in nature—across the four clusters in this course. Noteworthy data were found in each cluster regarding SLOs that were mostly taught through practical activity prior to the pandemic, and taught through alternative means during the pandemic. For instance, in Reproduction, 85% of responding teachers taught “Observe, collect and analyze class data of single trait inheritance” through practical hands-on learning activities prior to the pandemic, and during the pandemic 50% taught this SLO through alternative activities not practical in nature. Learning activities like this which require practical investigation, skill development or student interactions are associated with the most striking differences before and during the pandemic. In Atoms and Elements, 94% of respondents taught “Experiment to determine indicators of chemical change” through practical work before the pandemic, while 56% taught this through alternative activities during the pandemic; in Nature of Electricity, 97% used practical activities to teach “Construct electric circuits in series and parallel using schematic diagrams” pre-pandemic, while 60% used alternative methods during the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

pandemic; and finally, in Exploring the Universe, 62% reported teaching “Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects with altitude and azimuth” through practical activities prior to the pandemic, while during the pandemic, 38% reported teaching this SLO through different activities not involving practical work. In my experience, learning activities like these can be effortlessly taught with student hands-on experience, but are much more difficult to teach without such opportunity.

Other findings show a greater percentage of teachers taught some SLOs through alternative means during the pandemic, versus through practical means prior to the pandemic. For instance, 73% of teachers taught the Reproduction SLO “Investigate environmental factors and personal choices that may lead to genetic mutations” through alternative means during the pandemic, while 39% taught this SLO through practical means prior to the pandemic. Similarly, in Atoms and Elements, 74% taught “Investigate the development of the periodic table as a method of organizing elements” through alternative activities during the pandemic, while 64% taught this through practical work before the pandemic. As SLOs like these are more attainable through other forms of investigation such as Internet research, questions as to whether or not restrictions impacting practical work opened opportunity for teachers to teach more of the concepts and attitudes in some SLOs, or if the shift to alternative means simply allowed teachers a way to continue teaching science to their students are important for Phase II discussions.

While evident in the data that many Grade 9 science teachers implemented alternative methods to teach some SLOs during the pandemic lockdowns and restrictions, other points of discussion about the ways teachers limited and/or adjusted practical learning opportunities during the pandemic are important. First, a general trend was seen within certain clusters, where a shift was noted in how teachers taught some of the SLOs during the pandemic. In the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Electricity unit for example, 78% of responding Grade 9 teachers indicated using practical work to teach “Construct one or more electrostatic apparatus like a pie-plate electrophorus, and explain how they function” prior to the pandemic, while 28% indicated teaching this SLO through alternate activities that were not hands-on during the pandemic. Whether teachers were unable to provide alternate means for students to learn SLOs like this one during pandemic restrictions, or did not teach some SLOs during the pandemic was important to the research questions and of interest for Phase II discussions. This general shift was identified in the Reproduction unit as well, but countered the trend seen in other units, with an increased proportion of teachers who taught some of the SLOs through alternate means during the pandemic. It was determined that this positive shift most closely accompanied SLOs that might be more adaptable to alternate learning activities not involving practical work.

Second, the proportion of teachers who taught some SLOs through practical work prior to the pandemic relative to the proportion who taught the same SLOs through alternate methods during the pandemic remained generally stable in some cases. For instance, 82% of teachers taught the SLO “Compare and contrast the function of mitosis to meiosis” through practical work prior to the pandemic, and 85% taught this SLO through alternate activities during the pandemic; while similarly 85% taught “Relate the reactivity and stability of different families of elements to their atomic structure” through practical work pre-pandemic, and 81% taught this SLO through alternate strategies during the pandemic. Notably, in my experience, the concepts and skills required to learn SLOs such as these are attainable through a variety of learning activities that do not require practical work or student interaction.

A third feature was noted in participant responses regarding some SLOs including “Differentiate between physical and chemical changes”, and “Construct electric circuits in series

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

and parallel using schematic diagrams”, in which a pronounced 97% of teachers reported teaching via practical work pre-pandemic. In order for students to learn some of the concepts and skills in SLOs like these, in my experience, practical work is not only incredibly beneficial, it may be necessary—in keeping with the reported practice of 97% of respondent teachers. Another SLO also requiring practical action to attain yielded a significantly dissimilar response from participants, however. Only 41% of respondents taught “Observe the motion of visible celestial objects and organize collected data, such as tracking the position of the moon/planets over time or sunrise/sunset data” through practical work prior to the pandemic, while 24% taught this SLO through alternative means during the pandemic. The nature of this SLO means students would likely be doing the learning activity at home, as tracking the position of the moon would occur at night. This raises the question as to why less than half the responding teachers taught this SLO prior to the pandemic and why an even smaller proportion of teachers taught this SLO during the pandemic—when students would not have been restricted from the night sky. Questions regarding the choices teachers made while teaching this unit are important for the Phase II discussions.

Survey Questions 29 – 30

29. Prior to the COVID-19 pandemic, which of the following specific learning outcomes did you teach through “hands-on” learning activities/practical work in your Grade 10 science classes? (Select all that apply if you taught Grade 10 science)
30. Since the start of the pandemic in March 2020, which of the following specific Grade 10 learning outcomes did/do you teach using different/alternative learning activities not “hands-on”/don’t involve practical work? (Select all that apply if you taught Grade 10 science)

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Table 18

Survey Questions 29 – 30 Responses

Grade 10 specific learning outcomes (SLOs) that were taught through “hands-on” learning activities/practical work prior to the COVID-19 pandemic, and through alternative learning activities since the start of the pandemic that were not hands-on/did not involve practical work:			
	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
Dynamics of Ecosystems:			
Illustrate and explain how carbon, nitrogen, and oxygen are cycled through an ecosystem	83	73	-10
Construct and interpret graphs of population dynamics	89	76	-13
Observe and document a range of organisms that illustrate the biodiversity within an ecosystem	80	55	-25
Investigate how human activities affect an ecosystem and use the decision-making process to propose a course of action to enhance its sustainability	66	67	+1
	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
Chemistry in Action:			
Investigate the Law of Conservation of Mass, and recognize that mass is conserved in chemical reactions	91	72	-19
Investigate and classify reactions as synthesis, decomposition, single displacement, double displacement, or combustion	85	83	-2
Experiment to classify acids and bases, using pH and indicators	94	69	-25
Investigate technologies used to reduce emissions	32	24	-8
	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
In Motion:			
Analyze the relationship among displacement, time and velocity for an object in uniform motion	97	76	-21
Collect displacement data to calculate and graph velocity versus time for an object that is accelerating at a constant rate	91	79	-12
Analyze the relationships among velocity, time and acceleration for an object that is accelerating at a constant rate	88	76	-12
Experiment to illustrate the effects of inertia in car collisions	88	62	-26
Investigate and describe qualitatively Newton’s Third Law	81	59	-22
Investigate conditions that illustrate the effects of friction on motion such as surface materials	59	52	-7
Investigate the factors that influence braking distance	78	48	-30
	Teacher Response (%)		
	Pre-Pandemic	During Pandemic	Change
Weather Dynamics:			
Explain effects of heat transfer within the atmosphere and hydrosphere on the development and movement of wind and ocean currents	90	83	-7
Collect, interpret and analyze meteorological data related to a severe weather event	71	50	-21

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The responses of Grade 10 science teachers to these two questions revealed a similar picture to the Grade 9 data in Questions 27-28, in that prior to the pandemic a large proportion of teachers taught many of the SLOs through practical work, and during the pandemic a smaller, but notable percentage reported teaching these SLOs through alternate learning activities not practical in nature across the four clusters in this course. This finding was pronounced in the data of several SLOs, and in one example in Dynamics of Ecosystems prior to the pandemic, 80% of responding teachers taught “Observe and document a range of organisms that illustrate the biodiversity within an ecosystem” through hands-on learning activities, while during the pandemic 55% taught this SLO through alternate activities not practical in nature. Given the nature of this SLO, students might make such observations in some natural habitat like a schoolyard, nearby park or pond, or perhaps on a field trip—all accessible prior to the pandemic. During the pandemic however, students might have had access to such environments but most likely without a teacher to direct and guide their learning activity. As over half of the responding teachers chose an alternate activity to teach this SLO its importance to them is clear, but it is also likely, based on my experience, that students would not learn the concepts, skills and attitudes in this SLO if they were not observing and documenting biological organisms in an authentic ecosystem. Other noteworthy responses with a comparable finding include an SLO in Chemistry in Action where 94% of responding teachers taught “Experiment to classify acids and bases, using pH and indicators” through practical work pre-pandemic, while 69% taught this SLO through alternate activities during the pandemic. The importance of this SLO is evident as 94% of teachers had students do practical work to learn it when experiments were available to them, and while a great proportion continued to find ways to teach the concepts during the pandemic, students would not have opportunity to learn procedural skills acquired when experimenting with

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

indicators and solutions, or while collaborating with other students. From these examples and aligning with the Grade 9 data, a large proportion of teachers taught the Grade 10 SLOs through practical work prior to the pandemic; while a reduced but significant proportion of teachers implemented alternate methods for teaching these SLOs during the pandemic—suggesting their importance to science teachers.

Other noteworthy data with a similar finding in the Grade 9 responses, suggest that these teachers felt that concepts and skills required to learn some SLOs could be attainable through a variety of learning activities that do not require practical work. For instance, 66% of Grade 10 teachers reported teaching one such SLO, “investigate how human activities affect an ecosystem and use the decision-making process to propose a course of action to enhance its sustainability” through practical work prior to the pandemic, while an equivalent proportion, 67%, indicated they taught this through alternate activities during the pandemic. This finding isn't surprising to me since students do not require practical work to learn the concepts and attitudes inherent to this SLO, and might do selective reading or online research instead. Questions however, about what practical activities teachers utilized to teach this SLO and others like it prior to the pandemic; and what alternate approaches were selected or created during the pandemic are important to the Phase II discussions with teachers.

Additional questions from the Grade 9 and Grade 10 data also arise: How did teachers teach the SLOs if they didn't implement alternate learning activities when restrictions to practical learning were in place? Were teachers limited to teaching fewer SLOs during the pandemic, particularly if unable to find or develop alternative methods or to make viable adjustments? What types of alternative learning activities did teachers turn to when teaching the SLOs in Grades 9 and 10 science through the pandemic, and moreover, to what extent did these

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

activities allow teachers opportunity to promote student scientific literacy? Additionally, how did teachers teach the Grades 9 and 10 SLOs of a practical nature, if they didn't employ practical work? For instance, in Grade 9, how did 78% of teachers teach students to "Construct one or more electrostatic apparatus, like a pie-plate electrophorus and explain how they function"; or 88% of Grade 10 teachers teach "Experiment to illustrate the effects of inertia in car collisions" without experiential learning opportunities? Expanding on the latter example from the In Motion unit, investigating, experimenting, observing and analyzing are often required to learn the physics concepts, skills and attitudes in this cluster.

Summary of Phase I Findings

The Phase I data collected from 58 Grades 9 and 10 science teachers from urban and rural school divisions in Manitoba who responded to the survey revealed information helpful to answering the Phase I sub-questions and the main research question in this study. From the teacher responses, important differences in teaching Grade 9 or Grade 10 science prior to, compared with during the pandemic were identified. Most notably, there was a marked decline in the number of units taught in the Grades 9 and 10 courses during the pandemic, as many teachers reported teaching fewer units during the pandemic than they had prior to. Informing the first research question in this phase, teachers also largely prioritized chemistry and reproduction in Grade 9 science, and chemistry and physics in Grade 10 science, both prior to and during the pandemic, however, notably less priority was given to other units during the pandemic. A large number of teachers held very low priority for the Universe unit in Grade 9 science and the Weather unit in Grade 10 science prior to the pandemic, and strikingly, most reported to not teach these units at all during the pandemic. Other distinct shifts teachers reported during the pandemic included a decline in frequency in engaging students in scientific inquiry and debates

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

about scientific issues; a decline in focus on teaching general learning outcomes (GLOs); a shift in priority for teaching specific learning outcomes (SLOs); and a decline in teaching the Cluster 0 Overall Skills and Attitudes SLOs. While more teachers reported a reduced focus on the Cluster 0 SLOs, a small number of teachers did report a slightly increased focus on teaching these LOs. Specifically, Cluster 0 SLOs requiring student discussions were more adequately explored during the pandemic.

Of great significance to this study, most teachers indicated practical learning opportunities are necessary for Grades 9 and 10 students to develop scientific literacy concepts, skills and attitudes, yet, during the pandemic lockdowns and restrictions, their students were rarely able to participate in such learning activities, or to experiment and collaborate with their peers. In both Grade 9 and Grade 10 science a large percentage of teachers taught many scientific skills and procedural SLOs through practical work prior to the pandemic, while fewer indicated teaching these SLOs via alternative learning activities throughout the pandemic. Despite restrictions to practical learning, many teachers found alternate ways to teach a number of SLOs without practical work and adopted a shifted emphasis toward SLOs more attainable without hands-on learning experiences.

Phase II: Interview Findings and Discussion

To analyze the qualitative interview data in this study, as explained previously, I used comparative analysis between transcripts, via the construction of codes and code groups, to enable the interpretation of links, patterns, sub-categories, categories and ultimately themes in the data.

Following first level coding of the transcript data through constant comparative analysis, codes were grouped by type. Analysis of the eleven interview transcripts supported the

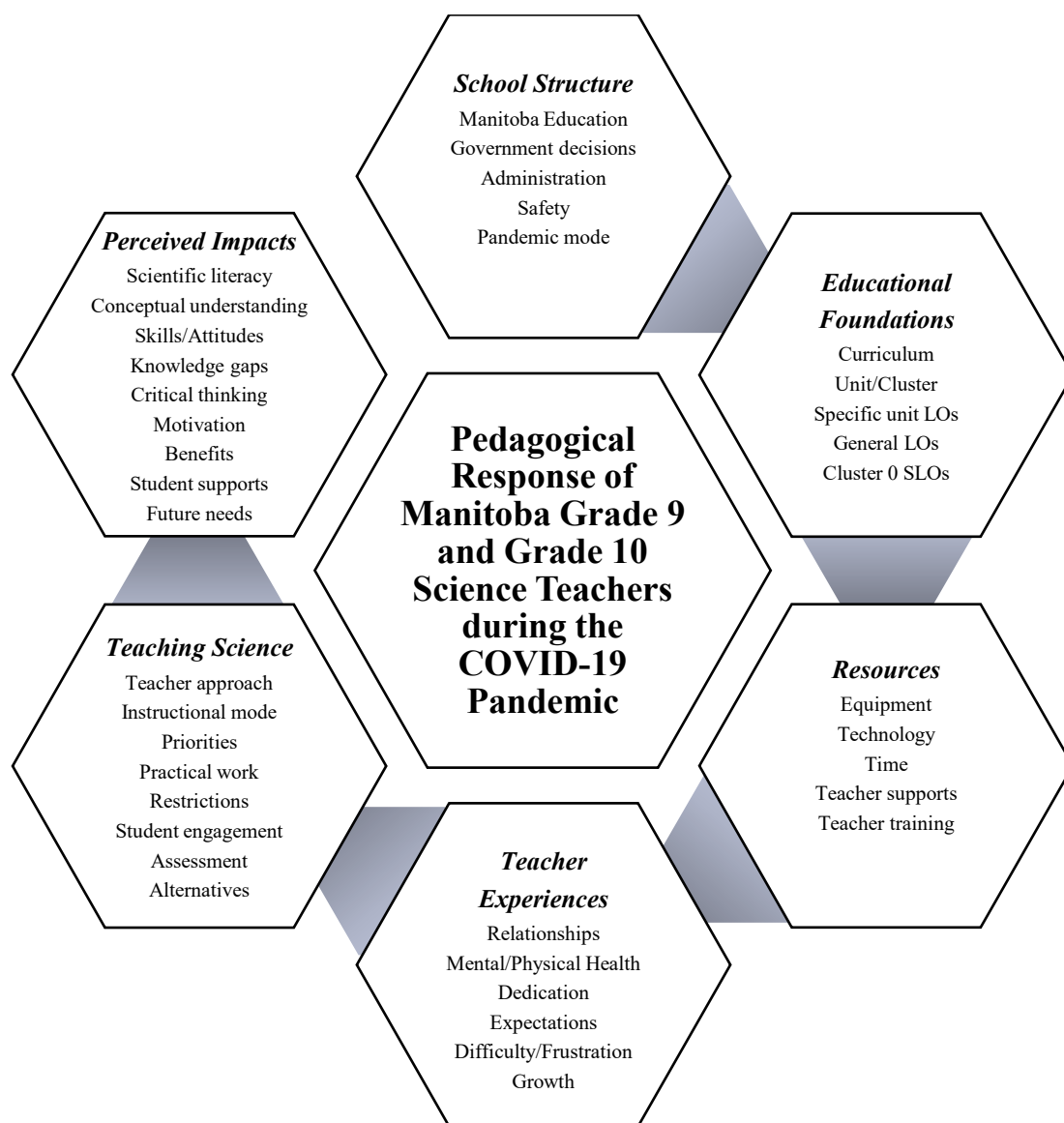
SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

development of 38 codes and six code groups: School structure codes (e.g., Manitoba Education, administration); educational foundation codes (e.g., curriculum, SLOs, GLOs); resource codes (e.g., technology, teacher training); teachers' experience codes (e.g., mental health, growth); codes for teaching during the pandemic (e.g. teacher approach, restrictions); and learning impact codes (e.g. skills/attitudes, scientific literacy). Code groups, codes and abbreviations used in the phase two data analysis are presented in Appendix E.

Categories were formed as codes and code groups took shape from the teachers' interview responses: School structure and administrative decisions; science education foundations; supportive resources; and personal and professional teacher experiences were found to influence pedagogical decisions regarding what to teach in Grade 9 and Grade 10 science, and how to teach it—both prior to and during the pandemic. My analysis suggests that the first four code groups—school structure, educational foundations, resources and teacher experiences, had a vital, sequential and compounding influence on the fifth code group: Teaching science during the pandemic. I viewed the sixth and final code group: Perceived impacts on student learning, as the emergent result of the fifth code group.

The six code groups determined in the Phase II analysis are depicted in Figure 1, with the pedagogical response of Grade 9 and Grade 10 science teachers during the COVID-19 pandemic as the central phenomenon in this study.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Figure 1.***Code Group Map***

After code groups were confirmed through constant comparative analysis of the Phase II data, they were organized systematically to describe emerging ideas and descriptive categories. The first four code groups—school structure, educational foundations, resources and teacher experiences were confirmed as compounding sub-categories, and united under the first emergent main category: Factors underpinning the priorities of Manitoba Grade 9 and Grade 10 science

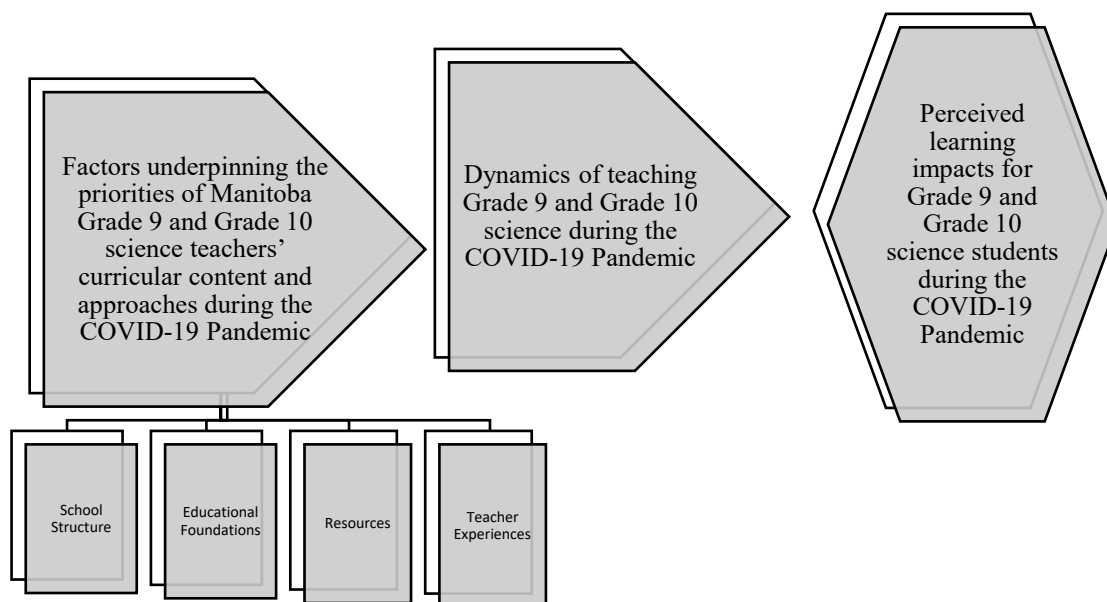
SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

teachers' curricular content and approaches during the COVID-19 pandemic. Evidence to support the collective influence of these four sub-categories on the pedagogical decisions made by Grade 9 and Grade 10 science teachers during the pandemic is found in the numerous quotes, multiple perspectives and divergent views shared during the Phase II interviews.

In my analysis, the complex myriad of elements as Manitoba Grade 9 and Grade 10 science teachers made pedagogical decisions and implemented them during the COVID-19 pandemic were identified as the fifth code group which I saw as a distinct second category: Dynamics of teaching science during the COVID-19 pandemic. My coding of the interview data suggests that curricular teaching priorities coupled with instructional modes and approaches to engage science students with alternate learning activities while restrictions to practical learning were in place, were adjusted throughout the pandemic's stages. The data connected with this category was helpful to extend understanding to the Phase I research questions and to inform the first Phase II research question.

The third and final category: Perceived learning impacts for Grades 9 and 10 science students during the COVID-19 pandemic, emerged from the second category, and is of critical value to answering the second Phase II research question and main research question guiding this study.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Figure 2**Categories and Sub-categories**

Following the confirmation of categories, I identified an initial set of seven themes from the interconnections between the categories throughout the sequential explanatory Phase II data analysis. While initiating theme development in early data collection through field notes and memos, as I coded and categorized data, themes were confirmed in sequential alignment with my research questions. I found additional evidence of these themes while conducting the integrated analysis. These seven themes are central to guiding the discussion of the Phase II findings:

1. The professional and personal experiences of these Grades 9 and 10 teachers seemed to have significant impact on their decisions regarding what they teach and how they teach it, and these experiences were dramatically different prior to and during the pandemic.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

2. The rapid transition to remote teaching with the arrival of the pandemic required urgent upskilling for these teachers to adopt new technologies to teach their students, before they could consider science-specific pedagogy.
3. The curricular units and LOs these Grade 9 and 10 science teachers prioritize changed during the pandemic in response to a number of factors.
4. Practical learning experiences were valued by these teachers to advance student scientific literacy—and teaching Grade 9 and 10 science without them during the COVID-19 pandemic was exceptionally challenging.
5. These teachers adjusted their instruction and assessment in response to limitations on practical and student cooperative work during the pandemic, providing students with various alternative learning activities but remaining significantly reliant on digital technologies.
6. These teachers reported students were less engaged in their learning when alternative approaches to practical learning were utilized.
7. These teachers perceived student learning gaps resulted from limited opportunity to learn science through alternatives to practical work during the pandemic; and perceived scientific literacy gains for Grade 9 and 10 students were inferior to those previously achieved.

A discussion of the Phase II findings around each theme follows, with references to the relevant literature, the Manitoba science curriculum documents, and my personal teaching experiences.

As indicated previously; in order to do justice to the significance of the participant responses and to provide a thick description of the data interpretation process, I included many verbatim quotes from each participant, (e.g., P1 – P11) to support the emergence of the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

categories and themes. These contributions may be representative of similar or dissimilar opinions of participating teachers, or striking language with respect to how ideas are presented, or both. Transcription notations have been included within participant quotes: Italics for verbal emphasis; and square brackets for verbal descriptions of participant gestures or text clarification.

Theme One: The professional and personal experiences of these Grade 9 and 10 teachers seemed to have significant impact on their decisions regarding what they teach and how they teach it, and these experiences were dramatically different prior to and during the pandemic.

Teaching experiences prior to and during the COVID-19 pandemic were described by one teacher as “a *completely different battle*” (P5), and this distinct challenge dominated the interview discourse. “I’ve always loved teaching and working with kids and *doing* science, it’s one of life’s greatest joys, but I *hated* teaching science during the pandemic” (P1) explained another while emphasizing the general view shared amongst the Grades 9 and 10 science teachers. Understanding the novel experiences of this group of Manitoba Grade 9 and 10 science teachers throughout the COVID-19 pandemic is mandatory to understanding their pedagogical response.

All of the teachers shared their personal stories associated with the challenges of teaching during the pandemic and detailed accounts of their professional struggles teaching science, along with the array of novel professional and personal challenges which persisted throughout the pandemic. According to Hughes and Lewis (2020), teachers’ decisions are shaped by factors related to the teachers themselves such as their beliefs and identities; their curriculum materials and agency to implement them; and context. Within the pandemic context, teachers were burdened with multiple stressors and new demands they were unprepared for (Reimers, 2022), which they explained, during the interviews, had impacted their pedagogy. Despite the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

difficulties, I got the sense that these teachers' dedication to teaching science remained steadfast: "Science teachers were adamant to give students the best they could" (P6), aligning with other studies that reported the tremendous efforts of teachers worldwide to continue to teach science during this unprecedented period (e.g. Aguirre & Selampinar, 2020; Giordano & Christopher, 2020; Marshall, 2022). Although teachers shared similar professional and personal experiences globally throughout the pandemic, understanding the unique lived experiences of Manitoba teachers while navigating pedagogical decisions to foster student scientific literacy was important to this study.

I identified a distinct difference between the experiences that teachers described at the start of the pandemic versus their later experiences and accompanying professional growth as the pandemic progressed. I felt this was evident in one teacher's response which also highlighted individual differences and needs of the teachers: "The difference in teachers...*Oh, my God. It was all over the spectrum at the start...the next year I got up to speed*". A discussion of teacher experiences early in the pandemic precedes their later experiences, beginning with the first period of pandemic teaching from March through June 2020, which teachers described as generally confusing and exceptionally difficult. One indicated:

At the start of the pandemic, that whole first March till June, I wouldn't even call it teaching, because *I didn't know how to do it*. I don't feel I had the tools to be able to do it (P9).

While these science teachers entered March 2020 as trained and experienced professionals with autonomy and confidence to make pedagogical decisions in the best interests of their Grades 9 and 10 students, when March ended, all felt untrained and confused about how to do their job.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Another teacher expressed the trepidation that accompanied the professional uncertainties they felt at the start. I related to this experience while I was teaching in March 2020,

You kind of felt like you didn't really know how long you were going to be out for, and initially most of the kids did nothing because they thought they were coming back after spring break. I know for teachers, we felt a lot like that, too... like after spring break things will change, we're gonna miss a couple of weeks, whatever, we'll figure it out (P5).

During spring 2020, many educators from various countries believed the pandemic was a temporary emergency that would not require major changes in education systems (Kosaretsky, 2021). As a result, most teachers did not invest in learning and changing pedagogy to adapt to the new reality, as there was deep uncertainty regarding how long schools would be closed. “It was a big stand still” (P2) explained one experienced teacher, describing the state of paralysis they felt with their colleagues as they wondered what would happen next. “I initially sent my kids home with two weeks worth of stuff when we went into lockdown” (P9) another teacher explained. This “stuff”, P9 explained was a previously printed collection of learning activities, readings and worksheets for normal lessons, and this teacher added “I have *no idea* how many kids used these, maybe 20%” (P9). Decisions about what to teach and how to teach it, while coping with the strange and stressful new reality of being locked down at home, were not of pressing priority for these teachers—just yet. While navigating initial adjustments at home and with family while “coping with work one day at a time” (P1), I noted that none of the teachers offered comments suggestive of school or administrative supports. As Lavonen and Salmela-Aro (2021) contend that principal’s support and motivating leadership served a key role supporting aspects of teacher’s well-being during the pandemic, such support may have aided these teachers

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

through some of their experiences. However, the combined impact of their unpreparedness and the precarious position threatening these teachers' ability to teach effectively took its toll, as one teacher summed up:

There were days where I was pretty stressed, and not feeling like much of a teacher to be honest, because I felt like I was just failing. And I really had to remind myself a lot that this is *not normal*, and it's not like you have a guidebook to go by (P3).

The extreme shift, from being, and feeling like a competent science teacher to “not feeling like much of a teacher” (P3), in my view was a horrific experience that challenged this teacher's professional identity, well-being and mental health. Manitoba teachers were among the global population of teachers sharing the same issues, while going through this seismic change in education (ICET, 2020). Unsurprisingly, other teachers interviewed expressed similar emotion, and worried about not being able to adjust appropriately without adequate training, guidance and supports to make suitable pedagogical decisions, and moreover—of failing to teach science to their students in an effective way. While teachers would likely have appreciated a guidebook, interview participants explained that pedagogical decisions became the sole responsibility of individual teachers, given limited collaboration with other science teachers while isolated in their homes. This is similar to findings in other studies (Tomasik et al., 2020; Zhang et al., 2020), and different learning experiences among Manitoba science students were therefore expected.

One unexpected event in Manitoba however, was shared by these teachers and seemed to disrupt the pedagogical decision-making capacity of all teachers: The Manitoba government's decision to freeze students' grades in March 2020 for the remainder of the school year. Every teacher that I interviewed felt distressed by this decision, expressing: “The thing they put out

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

March 20th, that defined everything” (P2). This was also supported by other teachers who commented that: “The government gave students an excuse to not do work, and I know it was a split-second decision when the world was tumultuous and we had no idea what was going to happen next” (P4); “They’ve been told it doesn’t matter what they do, so now they really have no interest” (P7); and,

The biggest hindrance to educating students during COVID when it came to Grade 9 and Grade 10 science was the fact that the government said right off the hop, their marks would not be important, and that made it really, really hard for teachers (P1).

Several participants also described how their concerns were exacerbated when the province announced one week later, that “No student will be held back due to the COVID-19 pandemic, but students must actively engage in learning” (Manitoba News Release, March 31, 2020). Participants’ frustration and aggravation were apparent in many interviews as the tone of teachers escalated when responding, and teachers articulated their concern for the magnitude of these government decisions on their practice, and on their students’ learning. “The simple government action allowed so many students to check out for the rest of the school year and I don’t know how long it’s going to be until we stop seeing the consequence of that moment” (P1); “Kids could *not* fail—take what you get from them and if they do it, they pass. If they put their name on it, they pass” (P8); and “Students had *no* incentive to do the work, because everyone would get their credit” (P4). A parallel finding was reported in Marshall’s (2020) study as students were granted an A without attending class. One participant, wrote in the Zoom interview chat, “Our administration told us to give our students the highest f@#king mark you can find a legitimate way for them to earn, if you have ANY EVIDENCE OF LEARNING” (P10).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Notably, I was given the same direction during the spring of 2020 which suggests that Manitoba teachers in at least two school divisions shared this experience. With the personal and professional pandemic experience already overwhelming teachers, it seems that having final grades and course completions assigned just six weeks into the half-year semester added great stress and complicated these teachers continued teaching experience and efforts to teach science.

Although these teachers lacked experience with school closures, and understandably did not know what to teach or how to teach it when the pandemic began in March 2020, these government decisions failed to afford teachers professional autonomy to direct learning and assessment in their science courses, unlike before the pandemic. As Audrain et al. (2021) described lower levels of autonomy are linked with reduced commitments to teaching, I believe the impact of this experience on these teachers' identity and confidence added a sense of fragility to their teaching during this period. From my experience teaching Grades 9 and 10 science in spring 2020, I think at least four factors underpinned the emotive reaction and responses of these teachers. First, while these teachers' comments might accentuate the perceived importance of course grades, for teachers, and likely for their students, parents and society, these teachers did not appreciate having these directives while they were struggling to teach, and they felt that the directives had a negative impact on students and learning. I agree with Davies (2020) who contends that students need fair assessment, and that part of learning and advancing metacognition is seeing the evidence when they have succeeded—which, according to these teachers, is usually a percentage grade at the end of the course. While expressing the view that Grades 9 and 10 learners may be motivated by grades, and anticipating difficulties engaging some students in their learning with course credits already granted, this was not the main concern expressed by these teachers. Rather, they voiced significant worry about supporting their teenage

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

students whose lives had been toppled, and that teaching science was secondary to caring for their students during this early stage of the pandemic. Similarly, several studies showed that teachers in other countries shifted their priorities to their students' well-being when the pandemic began (Reimers, 2022). Moreover, Audrain et al. (2021) contend teachers are increasingly asked to do more for their students, and on a global scale the pandemic further raised the expectations of teachers. When students needed counsellors for instance, teachers were thrown into a dual role without any training to support their students in multiple ways (ICET, 2020). Second, these government decisions undermined the teachers' professional autonomy by effectively eliminating their ability to make decisions regarding the assessment of their students from March 2020 to the end of the school year. While the Manitoba government's curriculum standards documents list important features of assessment: "In Senior Years science, as in other subject areas, effective assessment is an integral part of instruction and learning; is continuous and ongoing; is authentic, collaborative and reflective of meaningful science-learning processes; is focused on students' strengths; is based on how students learn; and is supportive of learning by offering clear performance targets to students (MET, 2000, p. 23); in the spring 2020 term, it seemed that the Manitoba government had temporarily suspended any opportunity for teachers to engage with these invaluable elements of assessment. Osborne and Pimentel (2022) contend that in science education, "Assessments can be high stakes for both teachers and students. Hence, they are read carefully as an important signal of the intent of the curriculum" (p. 248). While teachers were required to continue to plan lessons and to continue to teach, they felt denied of this integral component of instruction and learning—which in my view, challenged their teaching philosophies and their options.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The emotive responses of these teachers to this government decision hold deeper connotations about their interpretation of the curriculum standards and influence on their pedagogy and agency, which might only be recognized by others who shared this experience. One teacher expressed consideration to the importance of continuous, ongoing assessment for learning that focused on students' strengths during this early pandemic period, stating "I called all of my kids at home a couple of times, because I knew they really needed any positive feedback I could give them" (P3). Third, navigating government decisions to freeze student grades and assign course credit six weeks into the term was a new experience for teachers, which significantly impacted their capacity to make pedagogical decisions. What do you choose to teach, and how do you teach science to Grade 9 and 10 students for the remaining 14 weeks of the term, with course grades and credits already assigned—particularly if students lacked motivation to engage in their learning? Lastly, as Grades 9 and 10 science clusters are taught in the order teachers decide to teach them, in March 2020 when grades were frozen, students had likely completed only one unit in the course. For instance, my Grade 9 students had just completed their first unit, Nature of Electricity, which I always positioned first when teaching the second half-year semester since static electricity is more observable during Manitoba's cold, dry winter. I am aware that other teachers also address Grades 9 and 10 clusters in different orders, which likely resulted in Manitoba Grade 9 and 10 students learning different material from one another during the first six weeks of the 2020 spring term. Teachers were concerned about potential confusion for students and their parents, and for teachers at the next levels in science, as overall course grades in June 2020 represented student achievement in just one of four clusters. Further, while some students may have excelled, others may have struggled in the first units studied in spring 2020; and some teachers may have completed few assessments of learning. As

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Grade 9 science course grades are useful to inform teachers of student preparedness for Grade 10 science and of supports that may be required, and Grade 10 course grades are useful to indicate the readiness of students to embark on elective Grade 11 courses in chemistry, physics and biology; teachers feared that inaccurate representation of overall student achievement in Grades 9 and 10 science might be problematic.

Participants also explained that another government decision had additional impacts on their teaching experiences and further complicated their pedagogical decision-making: direction to limit remote teaching time with students (Manitoba News Release, March 31, 2020). Teachers expressed their concern for student contact time, "The hours the government stated for Grades 9 and 10 students was restrictive" (P3); "They asked us to limit screen time and lessons to twenty or twenty-five minutes" (P6). These teachers deeply grappled with the government's initial directives while professionally isolated in their homes, and while restricted from in-person communication with their school administrators, colleagues and students, their teaching job and decisions were daunting and some didn't know what to do. One teacher stated "Well, if it takes them ten minutes to log on, *like what am I going to do with them in ten minutes?*" (P9), echoing the worries my colleagues and I experienced in March, 2020. As Grades 9 and 10 science teachers had experience designing and implementing many diverse and meaningful lessons commonly one hour in length prior to the pandemic, they were challenged at the start of the pandemic to plan and teach effective science lessons of 20-25 minutes. Despite studies examining the impact of the pandemic on learning that have revealed that long hours in virtual classes were not desirable for teachers or their students (Lavonen & Salmela-Aro, 2021), and most can likely relate to the discomfort and difficulty of sitting at a computer for extended

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

periods; these science teachers felt the government should have afforded longer class times conducive to meaningful teaching and learning in Grades 9 and 10.

While the teachers expressed their frustrations with imposed limitations on their pedagogy by the Manitoba government one queried “It makes you wonder if other provinces, or teachers in other places have to deal with these ridiculous mandates?” (P9). While I found no evidence of grades being frozen in other jurisdictions, I became aware of different international approaches in educational governance that shaped experiences of teachers worldwide during the pandemic. Although some countries (e.g. Poland) adopted a single national educational strategy when the COVID-19 pandemic arrived (ICET, 2020), in contrast, Kosaretsky et al. (2021) described different scenarios were implemented in different regions of other nations (e.g. Russia) and a lack of political consensus in Spain resulted in the 17 Autonomous Communities implementing different policies and guidelines (Valle & de Olagüe-Smithson, 2021). Iwabuchi et al. (2021) explained how most public schools in Japan were unable to hold online courses, and some innovative local governments worked independently to mandate various instructional alternatives that included a shortened summer break and alternative classes in summer 2020. Similarly to some nations, educational governance differs in Canadian provinces, and it seems that Manitoba teachers experienced a unique set of challenges influencing their pedagogy.

As the pandemic progressed, different personal and professional lived experiences seemed to be intricately connected in underpinning the pedagogical decisions these teachers made, surfacing in responses such as: “We all had to be two meters apart, wearing masks...cleaning or sanitizing desks and whatnot between classes and stuff like that” (P2); “It was *terribly* stressful and my priorities vacillated between my personal safety, the safety of my students, and, lastly, my curricular objectives” (P1); and “My curricular objectives became low

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

priority” (P6). Although teaching during the pandemic brought a lengthy list of daily tasks and routines that took precedence over, and time away from teaching science; these participants indicated that safety of staff and students was paramount. While pedagogical decisions about teaching science to students and advancing scientific literacy were at the forefront of these teachers’ daily routines prior to the pandemic, unsurprisingly, it seemed that personal and professional pandemic demands meant these teachers had little time and energy remaining to think critically about their pedagogy.

Other teacher responses detailed stress and concern for their students, and their own families, over concerns about their pedagogy: “Before the pandemic we weren’t as concerned about our students and isolation or mental health, and during the pandemic that has been a forefront of concern for us, and that has definitely changed the way we teach” (P4);

As a parent who also has kids at home in elementary school, I had to be a parent from nine to three, so from seven o’clock each night till two in the morning I was making video lessons and finding all the links and getting everything set up, and I would have 4 hours of sleep sometimes, and then boom, up with my kids, trying to keep them engaged as well as answering all the emails that came from families and school during the day—it was hugely stressful (P3).

Educators globally shared similar experiences in breakout discussions during the Teacher Experience and Practices in the time of Covid-19; Valuing Teacher Voice ICET/MESH Symposium on October 8, 2020 that I attended, with resoundingly comparable messages: Teachers’ personal, emotional, and professional lives had drastically changed, but their goal to continue teaching their students remained the same. I felt that the teachers in this study demonstrated remarkable commitment, grit and resilience while working to sustain student

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

learning. Manitoba teachers experienced great personal and professional pressure, joining other educators globally (ICET, 2020) who reported their jobs changed immensely and that they worked around the clock with little time for family or self. All of the teachers were in agreement that teaching science during the pandemic was an incredibly stressful experience, but they remained focused and dedicated to doing their job. This was emphasized in the response of one teacher who was suffering with direct health impacts:

It was just so much, and my husband was like oh my goodness, this is ridiculous, how do you do this?... I just, I can't fail...there's no way I'm *not* going to do this well, and so that's the stress on myself, right. *I was dying*. I was. I started getting migraines. I would be off work various times because they were incessant and there was no way to get rid of them, and it was just from stress. I have kids to take care of. I'm trying to take care of their mental health as well, and their education, and then I have yours, and I care about you. But you're not my children, but I'm trying to do my job (P1).

Along with a multitude of mental health concerns for the student population reported in other studies (Hoffman & Miller, 2020; Lavonen & Salmela-Aro, 2021), teachers in some contexts reported a “workload that more than doubled” (Stephenson, 2021, p. 9) during the pandemic. Teacher mental health concerns significantly impacted workplace productivity (Enns, 2021)—and observations of “teacher burnout [were] on the rise” (Manitoba Teachers' Society, 2021, p. 20). These reports are similar to the results of a nationwide US study conducted by Gicheva (2022), which revealed pandemic instruction was more taxing on teachers, and the demands and higher workloads led to reduced morale and increased burnout.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Considering these Manitoba science teachers made critical pedagogical decisions under these remarkably stressful circumstances, it is worth reporting that most of the teachers indicated an overall general satisfaction with the job they had done. One teacher stated, “I feel like I did the best I could with what we could do” (P3), while another described an overall sense of personal and professional growth through their pandemic experiences:

I've definitely learned a lot over the course of it and I think it's definitely led to a lot of creativity and problem solving on my part... *this was a complete shift in pedagogy...* it was a pretty incredible effort (P2).

As teachers described their knowledge gains through this complete shift in pedagogy, I noted this teacher's learning aptly resulted from new and deep involvement in their experience—which Petersen and Kolb (2018) emphasize are required for real learning. I also noted that the general perception of adequacy to teach science during the pandemic held by some teachers that I interviewed was often without reference to advancing student scientific literacy.

Understanding the collective personal and professional experiences of these Manitoba teachers throughout COVID-19 was essential to understanding their capacity and autonomy to make decisions about what to teach in Grades 9 and 10 science, and how to teach it. The single-most influential experience however, was the one that upended science education worldwide (Valle & de Olagüe-Smithson, 2021) and the lives of Manitoba Grade 9 and 10 science teachers: The sudden change to remote pedagogy that they were untrained and unprepared for, that prefaced “the biggest unplanned educational experiment ever seen” (Soares, 2020, p. 3397).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Theme Two: The rapid transition to remote teaching with the arrival of the pandemic required urgent upskilling for these teachers to adopt new technologies to teach their students, before they could consider science-specific pedagogy.

All participant teachers described the abrupt, drastic change in teaching mode they experienced in March 2020—going from in-class instruction, in which teachers were expertly trained and skilled; to the demanding mode of remote instruction, in which they lacked training and expertise, as incredibly difficult. Scholars reported that teachers worldwide had similar experiences as they were thrust into an emergency teaching model most were unfamiliar with (e.g. Burgos et al., 2021; Gajderowicz & Jakubowski, 2025; Valle & de Olagüe-Smithson, 2021). One participating teacher's response seemed to capture the magnitude of the experience:

It was like being in class with students one day and jumping into an online world where I had *no idea* what I was going to even do. I didn't know about Microsoft Teams or anything like that, so it totally took my teaching philosophy and flipped it upside down.... We now have the document cameras, I have the laptop, we have all these things in place, Edsby [web-based K-12 management system]. We were just introduced to Edsby when this all happened. We are like machines with this now. Well, *most of us*, anyway (P2).

The general experiences described by this teacher at the start of the pandemic offer the general sense of “Panic-gogy” (Watts et al., 2022, p. 3) that teachers felt when the pandemic began; and the general sense of comfort many later felt in surviving the online experience, as Donovan (2020) proposed would eventually occur. The expectations on teachers to swiftly transition into remote teaching as governments directed the education of children to continue; raised the profiles and digital expectations of teachers globally (ICET, 2020; Dong et al., 2020). Teachers

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

were required to adapt immediately to a new teaching paradigm that involved using online teaching platforms and course management systems utilized in their schools and school divisions, such as Google Classroom, Edsby, Microsoft Teams or Zoom—which as McKnight et al. (2022) identified in a US study, many teachers were unfamiliar with or had never used. Lavonen and Salmela-Aro (2021) suggested teachers with experience or better equipped with digital skills were more likely to be engaged with new technologies in their remote teaching, while those struggling with new “digi-pedagogy” knowledge, skills or platforms (p. 105), were more likely to feel burned out.

Despite their inexperience with these tools, the participants in this study described that they had little choice but to become proficient with them in their daily routines to record attendance and grades, to communicate with students and their parents, and to teach science—with some new skills enduring. According to one participant teacher:

I learned some skills I probably wouldn't have... all the teachers got everything set up on Google Classroom, and that was something I hadn't done. So, it kind of forced me to learn all of that Google Classroom end of it, and I continue to use that now (P7).

This rapid digi-pedagogy upskilling was crucial for teachers to teach their students throughout the various stages and modes of remote, BL and restricted in-class instruction throughout COVID-19. As each instructional mode required its own unique set of tools, scholars recognized the need for teachers to develop specialized skills for their effective implementation (Graham et al., 2019)—but the Manitoba teachers who participated in this study shared that they lacked training and experience with any of them. Valle and de Olagüe-Smithson (2021) suggested insufficient training and limited proficiency in the use of online platforms or interactive

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

audiovisual material meant teachers required online tools and supports. As Marshall (2022) found over 90% of teachers surveyed in a US K-12 study had never taught online prior to the COVID-19 pandemic and fewer than 2% had training in remote pedagogy, it was not surprising that these Manitoba teachers were untrained and inexperienced; nor that Marshall reported a six-fold increase in views for online support sites like Microsoft Teams occurred from February to March 2020. While teachers worked to improve their digi-pedagogy, Lavonen and Salmela-Aro (2021) pointed out that knowledge and skills to support students' engagement, learning, and their well-being in online environments were also required. To add to the confusion for Manitoba teachers, teaching styles "had to change on the fly" (P6), as changes were frequent but varied between schools. "With the restrictions, there were just too many [different pandemic periods and teaching modes] to try and keep track of" (P11), while another teacher elaborated:

I feel like I had three different modes... remote; providing materials for students who did not have access to Internet.... We had no blended or synchronous/asynchronous teaching, not in our school (P3).

The changing pandemic climate that teachers experienced and adjusted their work and daily lives within was described by one teacher as generally haphazard, which further complicated their teaching:

We did remote. Then we set it up into cohorts and we figured it would be better to have kids in school every day... *everyone* got their opinions in.

Administration kind of decided to do an every-other-day plan (P5).

According to Carrillo and Flores (2020), the roles, competencies and interactions among all participants accompany effective remote pedagogy. Although administrators and teachers alike were untrained and inexperienced, the Internet allowed schooling to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

continue—but educators had some catching up to do. Dube (2020) reported that some teachers lacked the knowledge and skills to operate a computer, and while the participant teachers were all skilled with this tool, as the pandemic progressed they described the predicament they were in as one teacher captured: “Full remote, was a *learning curve*” (P4). Other teachers elaborated: “No one knew any of the tech going on” (P2); “We were treading water with trying to learn all the technology” (P9); “We didn’t have anything set up, we didn’t have document cameras, we didn’t have anything” (P8); “The tech was new and glitches were frequent” (P5). The teachers’ responses align with the view of relevant scholarship that a lack of technical resources and expertise for remote teaching was an enormous hurdle to cross before any consideration of remote pedagogy specific to science instruction could be made. Moreover, such upskilling would require time and practice for teachers, and their students (Aguirre & Selampinar, 2020; Giordano & Christopher, 2020; Reicher, 2020)—but these were not afforded, according to the participants in my study.

As these teachers worked hard to keep up with daily lessons while learning and troubleshooting the technology required for remote teaching and communication with their students, they describe issues such as variable Internet access that surfaced across Manitoba communities and caused them to worry when students were unreachable, “Oh my goodness we had no idea what’s going on out there as so many students didn’t have connectivity” (P1) reported one concerned teacher. As Akoh (2018) contended, the assumption that technology can ‘level the playing field’ in the education of all students, particularly in remote communities is often misleading, and can in fact further marginalize students. As these Manitoba teachers were learning, and as I experienced, an intimate reliance on technology and the Internet supports a

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

demand for educational equities in digital access and literacy that are socially, economically and culturally embedded (Carrillo & Flores, 2020); but some Manitoba communities and schools lacked resources. Various technology issues included the practical limitations of equipment for communicating with students, as one teacher explained:

I definitely found full remote, um very difficult, because you can't really see the students. And because we had a limited bandwidth in the school, we couldn't turn on the cameras. We didn't know whether they were paying attention, if they were even tuned in, or if they walked away from their computer (P3).

Numerous scholars described significant and comparable issues worldwide as teaching remotely depended upon connecting with students via Internet access (e.g. Rossettini et al., 2021; Valle & de Olagüe-Smithson, 2021). Iwabuchi et al. (2021) explained most public schools in Japan were unable to offer online courses due to a lack of available technology in schools and student households, while Valle and de Olagüe-Smithson (2021) reported teachers in 50% of schools in Spain lacked the capacity and resources required to teach online. While Internet connectivity, digital equipment and funds for data joined the list of inequalities in provisions required to learn remotely from home, along with quiet workspaces and parents who had the time and capacity to support home schooling; Valle and de Olagüe-Smithson (2021) emphasized the additional disparity in how well teachers were equipped to manage the implications for their students. Further, Lavonen and Salmela-Aro (2021) explained that teachers felt stressed when their students had difficulties learning remotely, and as such, inequities among students had severe implications for teacher well-being. A variety of emergency plans were developed in some countries, to mitigate some of these issues and to support connections between teachers and their students during the pandemic. For example, subscription and data fees were waived by

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

telecommunication platforms and lessons were broadcast through public television and radio stations in Spain; and online provisions for teacher guides, textbooks and curriculum support lessons for Grades 10-12 were established along with study guides and materials for students with special needs or for those repeating (Valle & de Olagüe-Smithson, 2021). In some regions of Russia, computers and technology support services were made available for teachers and students; Internet service fees were reduced or provided free of charge to teachers and students; and express courses for remote teaching, training webinars and recorded video guides were provided to teachers (Kosaretsky et al., 2021). While a variety of national and regional educational support systems for remote teaching and learning emerged in other jurisdictions during the pandemic, Manitoba teachers were not afforded access to comparable forms of national or provincial support. To prepare teachers and students to teach and learn remotely in emergency situations, the inclusion of some remote instruction during a usual school year that requires the use of technology at home might be helpful.

While learning to adjust pedagogy in their specialized disciplines during the pandemic, as these Manitoba Grade 9 and 10 teachers described, they lacked training in remote science instruction—training that often requires months or years to develop and which scholars such as Kyne and Thompson (2020) suggest is necessary. Layton's (1991) perspective that developing subject-specific strategies to translate knowledge into effective instruction is a complex and often underestimated process seems to have been realized by these science teachers, as they found themselves struggling to teach science effectively to their isolated students after the pandemic began. One teacher said in frustration, "My lack of knowledge wouldn't allow me to do some of the things that I would normally be doing when I have kids in front of me" (P7). Describing how pedagogical and learner engagement strategies used in classrooms fail to translate directly to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

remote learning environments, Audrain et al. (2021) emphasized the difficulties teachers had guiding students toward appropriate self-regulation, metacognition, and active learning strategies while teaching remotely. Teachers could not conceive of ways to facilitate such learning, as two teachers explained: “You were really just delivering theory and trying to find some relevance which is not good pedagogy” (P5); “We weren’t really teaching, it was more like here are some notes, read them and try to learn” (P9), while openly expressing their shortfalls. Although science education should ideally bring about three kinds of learning: Enhanced conceptual understanding; enhanced procedural knowledge; and enhanced investigative expertise (Hodson, 1993), and many teachers know what science education should look like to achieve this—with students exploring, hypothesizing, gathering evidence, and drawing conclusions (Olson et al., 2014), the participants in this study could not provide this compulsory form of science pedagogy remotely.

The implications for students learning science and the development of scientific literacy while untrained teachers were fraught with learning how to teach science through remote instruction, were vast (Kyne & Thompson, 2020)—“remote teaching is a problem: it shortchanges students” (Stephenson, 2021, p. 9). When restricted from their trusted science teaching toolboxes, teachers, including myself and my colleagues struggled to adjust while seeking innovative solutions as one participant explained:

You can’t really do experiments and even demos through a camera. It’s very hard to set up.... And again, depending on our energies, for either that day or for that week, whether we could even set something up like that (P2).

As many of the teachers expressed and as I learned in the 2020 spring term, teaching science remotely through a camera is incredibly difficult, inquiry activities and experimentation are

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

nearly impossible, and demonstrations are impractical even if one is familiar with the technology.

As these teachers grappled to plan, create and deliver lessons to their science students in their isolated online workspace, they required suitable teaching resources for remote science pedagogy in Grades 9 and 10, confirming Hothi et al.'s (2022) perspective that "Innovations in pedagogy were the need of the hour" (p. 11). When asked if the curriculum documents were of some support to their efforts, one teacher revealed a level of desperation: "Yeah, like none... we just bought supplies off of each other through [Teachers] Pay Teachers, or shared resources, or made stuff up at 11:30 at night ourselves!" (P1). Although not considered a resourceful support for remote science education according to this teacher, the Manitoba science curriculum documents are foundational to the curricular units and LOs Manitoba Grades 9 and 10 science teachers continued to teach throughout the pandemic.

Theme Three: The curricular units and LOs these Grades 9 and 10 science teachers prioritize changed during the pandemic in response to a number of factors influencing their practice.

The rapid transition to remote teaching and learning required Manitoba Grades 9 and 10 science teachers on March 23, 2020, to join other educators globally to make immediate decisions regarding what to teach and how to teach their courses (ICET, 2020). Underpinned by their personal and professional experiences with the abrupt change in pedagogy, these decisions included which clusters and LOs they could teach through a remote platform, and all other pandemic instructional modes. The participating teachers' views were in general alignment with the scholarly perspective regarding what is most important to teach, to advance scientific literacy in the 21st century (e.g., Britt et al., 2014; Croce & Firestone, 2020; Valladares, 2021). However, while these teachers stated that they did their best to deliver their usual science programs, they

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

explained having little choice but to adjust significantly, and some abandoned entire units and large numbers of LOs with uncertain awareness of the impacts to their students' learning or overall development of scientific literacy.

A notable shift in these teacher' priorities during the pandemic was identified, as the teachers compared their pedagogy throughout COVID-19 with their previous practice, but one overarching message was made clear: These teachers struggle to teach the entire Grade 9 or Grade 10 science curriculum to their students at all times because they see the curricula as too immense. Examples of statements that were made are: "It's a massive curriculum, for both of them [Grades 9 and 10]" (P10); "There's just too much...I don't know anybody who teaches all four [units] in either grade" (P5); "I've only seen one school where they teach all four clusters" (P3); and "If you're going to do things well, really, I think we can only do three out of the four units" (P9). With 28 GLOs and 48 Cluster 0 Overall Skills and Attitudes SLOs in the Grades 9 and 10 science curricula, along with 67 SLOs specific to Grade 9 science unit content (MET, 2000) and 43 SLOs specific to Grade 10 science unit content (MEY, 2003), I generally agree with their perspective.

Before discussing the content taught in each course and the rationale behind changing unit and LO priorities during the pandemic, it is important to note that teaching priorities were pliable, as adjustments were made in response to the different pandemic periods and instructional modes implemented across Manitoba school divisions in order to accommodate changing pandemic protocols. Participants noted that the first pandemic term in 2020, for instance, was exceptionally difficult for teachers, and their course content priorities were still under consideration:

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

There were definitely some outcomes that I didn't do as much with, especially in that initial 2020 block in the spring. For example, with Motion, there was a lot of stuff that was going to be very difficult for kids to understand without seeing some of those things in person, and without them being able to connect to the Internet to even watch a video it was going to be pretty tough. So, there was a lot I left out in that particular unit that term (P2).

While articulating their inability to teach many LOs during this term, I believe this Grade 10 teacher (P2) offered a snapshot of the multifaceted decision-making that would be required of them throughout the pandemic: What scientific concepts would students struggle to understand without practical learning or demonstrations? How would technological issues support or interfere with student learning? Would video alternatives support or suffice for teaching some scientific concepts, skills or attitudes? What content should be included, or excluded, and what are the implications for students learning science and for their scientific literacy development? During this period, other teachers were simply unable to teach certain units, despite their priorities; and some students did not learn certain units, despite teacher's attempts to teach them. As one teacher put it:

I'm going to be really honest, in the Grade 10 that first year we only got to the Chemistry. We did Chemistry in class before March 2020 and were pretty much done when the pandemic hit. And we did the Ecosystems and Weather remotely through package work. Well, the kids that did the packages (P3).

Despite "In Motion" being a usual Grade 10 priority for this teacher, they explained that teaching it remotely without time to prepare was impossible during the 2020 spring term, opting to teach the Weather Dynamics unit instead when they normally wouldn't spend much time on it.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

According to Darling-Hammond and Hyler (2020), teachers required time to craft and practice new and effective pedagogies to promote scientific literacy which, early in the pandemic, many were not afforded—consequently rendering some teaching priorities impractical. It seems likely to me that this resulted in variable learning impacts for Manitoba students in this period. Adding to the variable outcomes for students and of additional concern as previously discussed, the overall mark students received in Grade 9 or Grade 10 science during the 2020 spring term was a result of their performance during the first six weeks of the course, typically reflecting just one of four topical clusters rather than their overall achievement in the course.

Although the 2020 spring term was fraught with complicated decisions, these teachers described the 2020-2021 school year as the most complex, with varying modes of instruction ranging from remote, to hybrid, to in-class with restrictions, and with the situation changing frequently. One teacher explained, “All of the varieties of how we had to physically be in the classroom or not in the classroom from September to that next June determined a lot of what you did and what you didn’t do” (P8); while another added that during times of blended learning “When we were teaching every two days, we had to cut some of the content so we just focused on the basics of the curriculum, and we also only did three units as opposed to four” (P9). As these teachers grappled to make important decisions like these, regarding what to teach and how to teach, most stated that they were overwhelmed with their professional sense of duty to provide a comparable quality of science education to their students, as they had before the pandemic. Other teachers added their views of what changed: “Before the pandemic it was much easier to get through the units, and to cover more outcomes in more detail” (P11); and “There was just no way to get through the curriculum [during the pandemic] (P1)”. While these teachers generally expressed their inability to teach the depth and breadth of their curriculum prior to the pandemic,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the pandemic greatly exacerbated the situation. It was importantly noted however that this inability to teach the curriculum might be more accurately described as their inability to teach what they prioritize as most important for Grades 9 and 10 science learners—which for participant teachers seemed to remain temporally steadfast throughout COVID-19.

As the pandemic progressed, so did the necessity to adjust and teach content of perceived value for students:

2021-22 was the year when students basically attended half days for most of the year. There was just so much interruption, and we focused on the big outcomes... [it] was a steep learning curve, but I think I got really good at it... the pandemic forced me to do that. *We had to* (P9).

As this teacher indicated, priorities for what they taught centered on what they considered most important for students, but these evolved throughout the pandemic periods akin to the “stop-gap-solution” Singal et al. (2021, p. 520) described as necessary, while teachers adjusted their pedagogy under pressure. As one UK study from the field of curricular reform reveals, when teachers are unaware of goals or are challenged by complex ideas in changing curricula, a reliance on existing practices and ways of thinking tends to guide their implementation (Hughes & Lewis, 2020). Although the change to curricula was forced by the pandemic emergency rather than the introduction of new curriculum, in my view these science teachers experienced a similar response when required to actively engage with curricular design, and turned to existing beliefs and practices.

Course content priorities in Grades 9 and 10 science align with what these teachers perceived as most important for science learners in these grades, evident in their responses to what clusters and LOs they taught both prior to, and during the pandemic. Establishing the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

content priorities in each course prior to the pandemic is crucial for understanding the subsequent changes identified during the pandemic, and serves as a backdrop for comparison while helping to expand the Phase I data to answer the first research question.

These teachers provided their Grade 10 priorities when queried in statements such as: “For Grade 10 science, chemistry is always number one, physics would be priority two, ecology priority three, and weather last” (P5); “Chemistry and physics were non-negotiable...there was an equal amount [of time], but less in the ecology” (P8); “I focus on the Motion and Chemistry units, and I usually do Ecosystems as well in full... I usually get half of the Weather unit in as well” (P10); and “in Grade 10 we all omit the Weather unit” (P2). Of strikingly low priority, it was clear that some teachers don’t teach Weather Dynamics: “Chemistry and physics were prioritized over ecology and whatever the other cluster is, um and *of course* the other one was completely omitted. We just didn’t bother with the other one” (P1). Unable to recall the subject of one of four mandatory units in the Grade 10 curriculum (MEY, 2003), this teacher joined all other participant teachers who ranked this unit and its SLOs of lowest priority for their students. Another teacher added, “Weather might have been addressed in Geography, um, so we didn’t do it” (P3). I think this is a concern since the broad concepts of weather may be taught in numerous contexts and courses including Grade 10 Geography and Science in Manitoba, but the focus of the former is on impacts for natural resources not the science of weather. Since Grade 10 science is the last required science course for students in Manitoba, I think the implications of its omission are significant, as students lose opportunity to learn the scientific concepts in the Dynamics of Weather unit that are critical to understanding the atmospheric science of the planet they live on. There is also lost opportunity to learn other content, in the Dynamics of Ecosystems unit for instance given teachers’ generally reduced priority for this unit. With Chemistry in

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Action and In Motion of primary importance overall, the Grade 10 participating teachers were in general harmony with their cluster priorities prior to the pandemic.

Similarly, the Grade 9 teachers' priorities were largely synchronized with their priorities prior to the pandemic as they all aligned with one teacher who expressed: "The chemistry is always number one" (P6). Other responses providing comprehensive representation of the teachers were: "I tend to prioritize reproduction and chemistry" (P3); "It was reproduction, chemistry, no astronomy and less electricity" (P2); "I would teach all four [units]" (P11); "I prioritized chem, and put less emphasis on astronomy" (P8); "The Universe is omitted in Grade 9" (P5); and "We don't even bother with The Universe in Grade 9" (P1). Overall, the Grade 9 chemistry unit, Atoms and Elements was a leading priority for teachers, along with Reproduction; while Nature of Electricity was of lesser priority, and Exploring the Universe, of minimal or nil priority. One teacher offered an enlightening comment which may be of some significance to understanding the priorities of Manitoba Grade 9 and 10 science teachers: "For teachers who have more of a biology major, probably the one that gets the least prioritization is electricity" (P2). I had learned firsthand as the Faculty of Education admissions officer at the University of Manitoba before I began teaching, that many teachers brought science degrees in biology, chemistry and physics into their secondary science teaching careers, over other branches of science such as earth science or astronomy. In my recent role as a University of Manitoba Faculty of Education Practicum Advisor, I again observed that most high school science teacher candidates had degrees in these three disciplines, but more often in biology. Grades 9 and 10 teachers bring their individual passions, knowledge and skills into their teaching, along with an informed awareness of the academic preparation required to be successful in their chosen fields of study. If a large number of Manitoba teachers have degrees in biology, chemistry or physics, I

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

consider that the units they prioritize in their teaching might be consequently influenced.

Regardless, the resulting implications of Grade 9 and 10 teacher priorities and their decisions to teach, or not to teach content, might carry long-term consequences for students' scientific literacy in the 21st century—to their future learning, their careers, and their personal lives. Some participating teachers expressed disappointment in the implications of their own priorities: “Yeah, it’s not fair to the students if we don’t teach any astronomy [in Grade 9], just like the Weather unit in Grade 10 right. It’s easy to skip that one” (P10). A comprehensive discussion of these potential impacts will be presented in context with changing teaching priorities during the pandemic.

In summary, the teacher’s unit priorities prior to the pandemic centered on three key findings in Grades 9 and 10: First, these teachers place greatest priority on teaching the chemistry units in both grades—Atoms and Elements in Grade 9, and Chemistry in Action in Grade 10. Next, Reproduction is of great priority and Nature of Electricity lesser priority in Grade 9, while In Motion is of great priority, and Dynamics of Ecosystems of lesser priority in Grade 10. Third, most of these teachers do not prioritize, and some do not teach the fourth units in each grade—Exploring the Universe in Grade 9, and Weather Dynamics in Grade 10. Generally, these Grade 9 and 10 teachers prioritized teaching units and LOs in the three key sciences: Chemistry, biology and physics, despite all four units being equally mandated in each curriculum (MET, 2000; MEY, 2003).

During the pandemic, although these teachers’ priorities generally endured, an appreciable shift was found as they adjusted what they taught in response to pandemic lockdowns and restrictions that prevented them from teaching some of the units and LOs. In overview and to preface an in-depth discussion of shifted priorities and the reasons driving them,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

three broad changes in these teachers' practice are core to this discussion: First, an overall reduction in depth and breadth of content taught in each cluster, which varied by necessity throughout different pandemic periods and instructional modes. This reduction was more pronounced for some units including Nature of Electricity in Grade 9 and In Motion in Grade 10, but extreme in others as many teachers abandoned entire units, specifically the fourth units—Exploring the Universe in Grade 9, and Weather Dynamics in Grade 10. Second, while teacher' priority for units in the three key sciences persisted, decisions about what LOs to teach or not teach in the three key sciences resulted in plummeting priority of LOs in the fourth units. Third, these teachers generally taught a reduced number of LOs in both Grades 9 and 10 during the pandemic, while continuing to prioritize unit SLOs over GLOs and Cluster 0 Overall Skills and Attitudes SLOs; and while many of these teachers did not pay close attention to, and some were unaware of the Cluster 0 SLOs before COVID-19, the pandemic struggles exacerbated this situation.

Despite numerous reasons behind their pedagogical choices, the potential implications of what teachers did not prioritize or teach, both prior to and during the pandemic may have significant consequence for student scientific literacy development—and for students taking Grades 9 or 10 science during the pandemic, perhaps even more so. As many scholars including Maia et al. (2021) stress the necessity for all students to become scientifically literate in order to think, judge, position themselves, make decisions and respond to relevant issues in their daily lives, for Manitoba students in their final mandated science courses in the province (MEY, 2003), the impact of teachers' pedagogical decisions might be significant.

While discussing their pedagogical decisions at length, these teachers cited a number of influential factors prompting necessary adjustments to unit and LO priorities throughout the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

pandemic's periods and instructional modes. These factors, with varying levels of significance include: issues with technology and Internet access; time constraints limiting the size of units, and number of LOs taught; a required adjustment to learning expectations favouring concrete LOs over complex LOs; preparing students for their next levels in science, or for life and future careers; difficulties teaching some unit SLOs, GLOs and Cluster 0 SLOs with restrictions in place; school or team decisions about curricula, instruction and common exams; safety issues for staff and students; and the nature of the Manitoba science curriculum documents themselves. A consecutive discussion of each of these factors influencing teacher priorities follows; with the exception of technology issues, which were previously discussed and coalesce with the other factors.

Time Constraints Limiting the Size of Units and Number of LOs Taught. To understand and appreciate how teachers' unit and LO priorities were influenced by time constraints during the pandemic, an overview of the Grade 9 and 10 courses provides a baseline context for discussion. A total of 110 hours of instruction time is assumed in both the Grade 9 and 10 science courses, and it is expected that each of the clusters (1-4) be assigned equal time (MET, 2000; MEY, 2003). In Grade 9 science, the suggested hours of instruction for each unit are: Reproduction, 28; Atoms and Elements, 27; Nature of Electricity, 27; Exploring the Universe, 28 (MET, 2000); and in Grade 10 science are: Dynamics of Ecosystems, 26; Chemistry in Action, 29; In Motion, 28; Weather Dynamics, 27 (MEY, 2003).

Regardless of curricular suggestions, most of the teacher's reported inadequate time to teach all units and LOs to their students during normal times. Government restrictions limiting daily contact time with their students during the pandemic along with other school disruptions and tasks that took more time including taking attendance for instance, meant even less time to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

cover the units and LOs they normally prioritized. Teachers struggled with lost time, as one explained in frustration: “Time constraints... we had lost *too many* days... interruptions in the school year would be the main reason why I would leave outcomes out” (P5). Other teachers revealed a similar priority when time was cut short: “Sometimes it just takes time... you gotta get your nuts and bolts taken care of first and get at least the core curriculum [taught]” (P2). As school closures significantly reduced effective curriculum time during the pandemic, Reimers and Schleicher (2020) reported a shift of teaching priorities in different countries and schools to center on either core curriculum content for student progression and literacy; or on cognitive, social and emotional competencies fostering student well-being. Joining teachers in some countries, while the teachers interviewed in my study cared about their students’ well-being, they prioritized teaching core curriculum content during the pandemic.

While describing how time constraints limited the size of units and number of LOs they taught before and during the pandemic, the specific clusters in the Grade 9 and Grade 10 science courses remained central to the interview discourse. As teachers made significant reference to particular Grade 9 and Grade 10 SLOs, a tally of SLOs in each unit helps provide the general scope for discussion. In Grade 9 science, the number of SLOs in each unit are: Reproduction, 18; Atoms and Elements, 14; Nature of Electricity, 24; and The Universe, 11; while in Grade 10 science the number of SLOs in each unit are: Dynamics of Ecosystems, 10; Chemistry in Action, 12; In Motion, 13; and Weather Dynamics, 8 (MET, 2000; MEY, 2003).

As previously indicated, the Grade 9 teachers were generally aligned in prioritizing two units: Atoms and Elements, and Reproduction; while they ranked Nature of Electricity third, and Exploring the Universe last. Referring specifically to one Grade 9 unit: “Reproduction on its own is a massive unit and you can’t even get to all the outcomes that they’re asking for” (P6), one

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

teacher was in consensus with others in that the overwhelming breadth of certain units took too much time away from others. Some teachers described time limitations associated with the large number of LOs and feasibility of addressing all of them, and one offered an example referencing four SLOs in the Grade 9 curriculum:

In Reproduction... [SLOs] 15, 16, 17, 18... these concepts are super detailed, and trying to get them to even understand the general idea of it so they can have an appreciation for what's happening in their own bodies...there's just so many huge chunks, so yeah, there's just *no time* to do all of them (P3).

While 7.5 hours of the total 28 hours suggested instructional time for Reproduction are designated to these four SLOs, of 18 in the unit (MET, 2000), from personal experience I agree with this teacher's perspective that substantial time is necessary to adequately teach these detailed concepts. Each requires thorough investigations and discussions, and is of great importance to student scientific literacy: human sex-linked traits such as colour-blindness and hemophilia; environmental and personal choices contributing to genetic mutations or changes in development such as fetal exposure to alcohol, radiation and overexposure to sunlight, toxins, hormone mimicry or food additives; Canadian and international contributions to research in genetics and reproduction fields such as the Human Genome Project or cross-breeding production of canola in Manitoba; current and potential applications and implications of biotechnologies including their effects upon personal and public decision making, including genetic engineering, cloning, and DNA fingerprinting. Without time to teach important SLOs they prioritize and that are critical to learning science within each discipline, Manitoba teachers cannot achieve what the Grade 9 and 10 curriculum documents set out for them: "To develop functional scientific literacy in all Canadian students" (MET, 2021).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Another Grade 9 teacher disclosed: “I do Electricity, but I mean, I do two weeks” (P5). I would say that two weeks for teaching the 24 SLOs of the Grade 9 cluster, Electricity, is an insufficient appropriation of course time to effectively teach this unit. I also note that 27 instructional hours are suggested (MET, 2000), and from personal experience I believe that amount of time is needed to effectively teach this unit. The Grade 9 teachers I interviewed generally agreed with the position of two who reported: “We tried to get through all of the electricity, but that was the one that we cut if we ran out of time. But, the other two [units], we would get through everything” (P6); and “I’ve always put more emphasis on the chemistry and biology units, and usually the electricity part... we usually get done the full three units” (P1). As teachers like these made hard decisions to leave out portions of the Electricity unit or other units, I noted that students might benefit from extra attention to other LOs teachers deemed more important, or even critical to their scientific literacy development or preparation for future learning in chemistry or biology for instance. Further, while confirming their reduced priority for teaching the Electricity unit given limited time to teach, references to completing “the other two” units, instead of three; and “three full units” instead of four, confirmed the low priority for the Exploring the Universe unit. The Universe unit and its LOs were frequently left out of Grade 9 science instruction. One teacher explained their perspective on this, stating:

Space, it’s nice to know, but it’s not completely essential in my mind. So, I do try to build it in throughout the course, pull up things that are happening...like a shuttle launch... and the kids do really enjoy it. But that’s where I trim some time for sure (P2).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

While making it clear this unit was not a priority and therefore a place to cut content, this teacher indicated that any inclusion was often in association with current events of interest to students, over the science of the universe that include SLOs concerning: historical perspectives on the relationship between Earth and space; scientific perspectives on the origin and evolution of the universe; how various technologies like robotics, the International Space Station (ISS), Canadarm, Hubble telescope, rovers and space probes have extended our ability to explore and understand space; Canada's participation in space research and international programs; and the impacts of space science and technologies on human life (MET, 2000, pp. 3.24-3.25). From my perspective, the importance of these SLOs, and their contributions to student learning cannot be understated— "global interdependence; rapid scientific and technological innovation... and the pervasiveness of science and technology in daily life reinforce the importance of scientific literacy" (MET, 2000, p. 1.2). I learned firsthand, that many Grade 9 students, with their smart phones in their pockets, value opportunities to learn about important new technologies in global communication systems that might impact their lives and future careers; and some have their eyes on the sky and minds open to the wonders and possibilities within our solar system, and the universe. For example, while teaching science in 2019, the Grade 9 students in my high school had opportunity to speak directly to Canadian astronaut, David Saint-Jacques while orbiting the Earth on the ISS. Amidst indescribable interest and excitement, a number of students asked their prepared questions over the speaker system in our auditorium and interacted with this astronaut through a communication feed extending from Winnipeg to NASA in Atlanta, the ISS, and back. Subsequently, it was of little surprise to our teaching team that one of these students decided to pursue a career in astronomical science. Simply put, all Manitoba students deserve fair opportunity to learn the science included in the mandated science curricula in their province to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

enhance opportunities for a thorough acquisition of scientific literacy—but the participant teachers suggested that they do not all get this chance. One teacher explained why:

The Universe is omitted in Grade 9, and in Grade 10 we all omit the Weather unit because if you want to provide enriched lessons with labs and activities, there's no possible way to get to all four units... and get into the depth and breadth that they want (P3).

Another teacher shared their unique perspective that linking astronomy with other units was both a way to save time, and valuable to promoting practical interdisciplinary views:

If you leave astronomy to the end, you usually run out of time...but I think the kids should have some idea of what links the chemistry and biology to it... Like why is space travel worth it? I like the kids to think about what we have for energy production in Manitoba versus the rest of the world, and why we would be reaching out to the stars (P8).

With an emphasis on important connections to other concepts taught in the Grade 9 course, this teacher's interdisciplinary view also suggested low ranking priority of the fourth cluster, Exploring the Universe in Grade 9 science; while other teachers emphasized a similar rank of the fourth unit in Grade 10 science, Weather Dynamics—and how teachers preserve time for the three other units that they do prioritize.

In Grade 10 science, one teacher described their detailed timeline: “During the pandemic I did not teach Weather Dynamics. I taught 8 instructional days in Ecosystems, 15 days In Motion, and 22 days in Chemistry” (P5). While teaching the entire Grade 10 science course during a normal period of time is challenging in itself, this teacher's priorities for 45 teaching days during one pandemic term excluded one quarter of the mandated course—the entire

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Weather Dynamics unit. While revealing disproportionate teaching priorities for the units and LOs in Grade 10 science when pressed for time, it was additionally noted that this teacher's quantitative log may have been intentional and useful for future reference and planning, or perhaps for student assessment and reporting. Another teacher echoed:

We didn't focus on any of the SLOs for the Weather cluster... we kind of, you know, set it off to the side, and if we had time, we would maybe talk about it in class, but not specify any lessons to it (P3).

While some teachers indicated time restrictions left them with little choice but to cut LO content from these fourth units, it was amply clear in the way they described their actions that little value or effort was placed on teaching these units or their LOs. Comparatively, the Grades 9 and 10 science teachers made no reference throughout the interviews to cutting any content from the chemistry units to save time for other units—as chemistry was the first ranking priority for all of them.

While most Grade 10 teachers were aligned in prioritizing Chemistry in Action first, In Motion and Ecosystems next, and Weather Dynamics last, despite maintaining these unit priorities during the pandemic teachers had to cut LOs within them. Some teachers opted to leave out SLOs perceived to take more time to teach, although among the most important for SL development. One Grade 10 teacher explained:

In Ecosystems for example, I focused on about three quarters of the outcomes...the ones that I cut out were to try and make it a bit shorter. So, I think it was maybe some of the last ones, like around bioaccumulation (P9).

The elimination of complex LOs like this one suggests that students would have been denied opportunities to develop critical thinking skills to complex problems or to practically apply the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

scientific knowledge learned. An understanding of bioaccumulation for instance, when chemicals become increasingly concentrated in biological organisms over time has become increasingly important for human health with the extensive use of pesticides; the increase in microplastic distribution; and elevating global emissions. In my experience, these complex issues that bear social and cultural significance require time to teach and time to learn, and often require practical work. Further, in my view, Grade 9 and 10 students should know that methyl-mercury concentrations are a concern in some Manitoba lakes and pose elevated risk to northern First Nations communities. To advance their scientific literacy, students should also understand how methyl-mercury enters the food chain and biomagnifies, and why pregnant women should minimize their weekly fish consumption for instance (MEY, 2003). Although bioaccumulation is introduced earlier in the Grade 10 Ecosystems unit (MEY, 2003, pp. 1.24-1.27), complex issues such as this one are usually prescribed in each unit's final LOs despite their apparent impact on the development of functional scientific literacy. Yet, in my experience some teachers do not teach the final LOs in a unit.

Another teacher expanded on the breadth of the Ecosystems unit: "You can spend three weeks talking about ecology... it's really, really broad... and it would be great if we could cover those outcomes, *but um*, we can't, because of time" (P1). With a contrary perspective of the size of this unit, another teacher stated "I find the Ecosystems unit smaller and believe there's fewer outcomes in that anyway" (P9), as perhaps reasoning for a demoted priority for teaching it. Importantly however, this teacher's view revealed an accurate perception of fewer SLOs in the Ecosystems unit. Yet, the comment fails to address either the complexity of the latter SLOs that may not have been taught, or the potential impacts of such losses on student learning. For instance, the tenth and final SLO in this unit requires students to investigate how human

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

activities affect an ecosystem; and to use the decision-making model to propose a course of action to enhance its sustainability while considering impacts on biogeochemical cycling, population dynamics and biodiversity. Five hours of the suggested 26 hours to teach this unit are assigned to this complex SLO (MET, 2000, pp. 1.24-1.27). In my view this amount of time is required to address the critical socioscientific issues (SSI) linked to human activities such as climate change, and important for students in their development of scientific literacy in the 21st century. Understanding the role that human populations hold on terrestrial, aquatic and atmospheric ecosystems, on important biogeochemical cycles such as carbon and nitrogen, and on global biodiversity, is imperative for 21st century learners in my opinion as they navigate their personal and societal responsibilities to protect them. As many scholars maintain, students learn best to address SSI through explicit practice addressing them (Morin et al, 2017) and teachers must prioritize these opportunities for students to learn science. Moreover, if learning opportunities found within SLOs like this one are of lower priority for teachers because they are considered too complex, or perceived to take too much time to teach, implications for the development of student functional scientific literacy are likely to result. Yet, the consequences of the pandemic meant time was a precious commodity for teachers, and other priorities emerged. Irrespective of how and why teachers make their decisions—limited time to teach all content, concern for teaching prerequisite concepts for future grades, common exams within schools, or perhaps the sequence of prescribed SLOs written within the curriculum documents; the impacts of these decisions might be considerable. Moreover, if students miss opportunity to apply important scientific conceptual knowledge, skills and attitudes necessary for developing scientific literacy while in Grade 9 and Grade 10, particularly if Grade 10 science is their final science course in high school, the impacts will likely be considerable. While students choosing to

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

pursue higher-level sciences might acquire conceptual understandings they miss while learning high school science as they further develop functional scientific literacy to apply to their chosen occupations and personal lives, Valladares (2021) suggests other students might carry lifelong deficits to understanding the real-world complex scientific issues facing society and themselves. In my view, such an outcome fails to serve the instructional philosophy presented in the Manitoba Senior Science curriculum documents that directs: “Programming should foster critical thinking skills and promote the integration of knowledge and application of facts to real-life situations” (MET, 2000, p. 17)—and overlooking any opportunity to provide this, disadvantages students.

Another teacher expanded the discussion on complex SLOs, joining other science teachers, myself, and multiple scholars (e.g. Allchin, 2014; Bencze et al., 2020; Pedretti & Nazir, 2011) who believe teaching current SSI in science augments functional scientific literacy. This is particularly evident when students have opportunity to apply their newfound knowledge, skills and attitudes in some practical way—even though the curricular organization of LOs might not support this. The idea that the curricular design itself suggests a prescribed teaching order for LOs, and might influence teacher capacity to address all of the outcomes while facing time constraints was considered in their response, as follows:

I think the hardest outcomes are the last couple... to make global connections, the real-world applications... the trickiest outcomes and the goal of what you want to get to but the hardest for the students. I almost wonder if the curriculum should look like, here's the big idea of this outcome, here's the goal of what we want to teach, and here's the pieces that we want you to cover. When you have 20 outcomes and they all are weighted the same, you can focus a lot of time on

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

things that are leading up to the grandiose destination that you want to get to.

And if you focus too much on all those little pieces, then you run out of time to

focus on what *really* is the point of this unit, the big idea (P4).

From this response and my experience, although some teachers may follow the consecutive layout of the curricular documents in their practice, most high school teachers and science teams interpret and adjust the curriculum they teach before designing and facilitating instruction. This approach is suggested in their curricula: “Clusters do not need to be taught in the same sequence as they appear in the document” and teachers are directed to use their own discretion to provide opportunities for students to achieve all LOs while emphasizing foundations, themes and the interdisciplinary nature of science (MEY, 2003, p. 28; MET, 2000, p. 3.3). As the “big idea” outcomes are positioned at the very end of the Grade 9 and 10 clusters despite arguably being the most important LOs for developing functional SL, if teachers teach unit SLOs in the order of their curricular appearance, crucial “STSE issues might be taught towards the end of a unit if the teacher got to that point” (Zoras & Bencze, 2014, p. 438). Crujeiras-Pérez and Jiménez-Aleixandre (2017) contend that student development of scientific literacy is significantly enhanced when students are in the center of the learning process, engaging in local and authentic inquiry and science practice—and such prescribed opportunities commonly appear at the end of each unit. One teacher suggested their priorities would change if the curricula were presented differently to support a big idea approach, and subsequently protect the most valuable SLOs for student scientific literacy gains:

If there was an emphasis on practical applications, or on sustainability to do with that unit and it was strongly emphasized by the curriculum and placed, say, near

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the beginning and repeated, maybe as a theme throughout, then I would place more emphasis on that (P11).

Yet, for experienced teachers, teaching the scientific competencies students need to develop inquiry, problem-solving, and decision-making skills necessary to make informed, critical decisions (MET, 2000) found in complex, big idea SLOs is challenging for some at the best of times:

Research skills and design skills are important. One year I did an inquiry project... let's all come up with our own experiment to grow beans or another vegetable and see if you can figure it out, but all those things require a lot of class time, *a lot of* class time, so I have to decide - am I putting emphasis on this? (P1)

Time considerations are critical as teachers plan and organize units, and some learning activities naturally require more time than others, such as inquiry-based learning in which students question, predict, observe, infer, measure, classify, experiment, collect, analyze and interpret data while developing fundamental attitudes of curiosity, skepticism, and creativity that are foundational to scientific literacy (MET, 2000; MEY, 2003). However, scheduling time to teach critical authentic SI activities that are an important process in learning science (MET, 2000) and for the development of functional scientific literacy is crucial (Allchin, 2014; McBride et al., 2004). Teachers are cognizant that their choices to prioritize particular LOs involving select concepts, skills and attitudes from the extensive lists in Grades 9 and 10 science, are unfortunately at the cost of time available for other LOs. But when teachers make decisions to leave out valuable SI or technological problem-solving activities from their teaching because they are too time consuming, the potential implications for learning foundational NOS and STSE

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

LOs important for scientific literacy are great. Teaching the foundational GLOs might take *a lot of* time, as accentuated in this teacher's response and more so if taught independently, yet are critical to fostering student scientific literacy (MET, 2000; MEY 2003). Moreover, building GLOs and Cluster 0 SLOs directly into instruction independently, where vast numbers of unit SLOs are at the core might not be possible however, given the demands of time required to teach them.

The general view participants expressed is that teaching all the LOs within a constrained time is a lofty task at any time (e.g., "Really, time is huge... I'd love to do them all but time is huge, *a huge factor*" (P1); "We just, we didn't have enough time to do what we normally would" (P4), but especially so for teachers new to the profession. For example, one participant with two years teaching experience said, "I would gloss over some, and do others in a lot more detail" (P3). However, other more experienced teachers had developed effective strategies to manage time demands, and the approaches of three teachers prior to the pandemic revealed significant confidence to adjust their curricula in the manner suggested by the standards document (MEY, 2003). While the majority of teachers said they were unable to teach all four units during the pandemic, one teacher explained: "I taught all four clusters in Grade 9 and Grade 10 sort of equally while tying units to each other. Like in Grade 10, Ecosystems ties so much into Weather, Chemistry ties so much into Ecosystems... I think they're all intermingled" (P7). This perspective might suggest an interdisciplinary approach of the four topical clusters similar to integrated STEM education (Wang et. al, 2020), where students work on real-world problems in the context of socially relevant complex situations of importance to their daily lives, that require knowledge and skills from multiple disciplines. I believe a creative teaching approach weaving critical connections between all four science topics in Grades 9 or 10 science could provide

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

compelling opportunity to advance student functional scientific literacy, while considerate of course time. Another teacher described a different method of grouping LOs to save time:

I did [include all the LOs], but... it's too overwhelming to do 20 outcomes for every unit. There's no way you can do them all thoroughly so I would print out the outcomes, cut them all up and group them into big idea chunks...and I know if I was teaching to what the main theme is behind these, this set of five outcomes, then I was covering everything (P4).

This approach allowed this teacher to develop a short list of critical or essential outcomes to construct their unit plan and learning activities. The approach would likely be useful when teaching courses with a large number of LOs, or when teaching a course for the first time.

Another teacher also combined LOs, while extending their reasoning to include backward design with a greater purpose of scientific literacy for daily life:

Sometimes because of time constraints, I would combine certain outcomes, so that I'm trying to do multiple things with an activity. I'm always in the mindset that learning has to have some sort of impact on their daily lives... so, I really like to start sometimes with the back end of those learning outcomes like how did this relate to your daily life in the kitchen; or doing meter readings and trying to figure out what they can do in their daily lives to conserve electrical consumption (P5).

Following clear curricular direction that the clusters and SLOs are mandatory but the order in which they are addressed is not (MEY, 2003; MET, 2000) provided opportunity for these teachers to manage time and cover all SLOs within a unit and likely enhanced scientific literacy outcomes for their students. This is an approach I shared with my colleagues when teaching

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Grades 9 and 10 science. This approach also suggests that teachers with more familiarity with the curriculum standards and those who approach their sequence and planning in a different way may be better positioned to respond to unexpected events. However, as most teachers taught fewer LOs in each unit as time constraints magnified during the pandemic, for those teaching SLOs consecutively this may have meant the elimination of the more complex SLOs listed at the end of the units—and consequent varied impacts for the scientific literacy of Manitoba students.

Impacts on student learning associated with the varying array of constraints for teachers that included time, changed in sync with changing pandemic periods and modes of instruction. Although the loss of teacher-student contact teaching time was most pronounced during periods of remote teaching, one teacher offered a quantified perspective of time lost during BL:

It was hard during the pandemic on their off days because they would seriously look at them as off days and so a lot of kids struggled, and teachers struggled.

The contact time was cut in half, and we can't cut the whole course in half, or else you'll drown next year (P6).

With instruction time extremely reduced throughout the pandemic and having a direct and substantial influence on what teachers chose to teach, some recognized their students might be left with gaps in their learning; and amongst this teacher's priorities was a clear concern to teach prerequisite knowledge to prepare students for higher grades. Understandably, teacher priorities shifted for several reasons and in various ways during the pandemic; but my analysis of these interviews also suggests that constraints in time to teach content they prioritize in Grades 9 and 10 science led some teachers to subsequently adjust learning expectations for their students.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Adjusting Learning Expectations and Teaching Concrete LOs Over Complex LOs.

The Grades 9 and 10 teachers described having little choice but to reduce their learning expectations for students during the pandemic, and as one explained, ensure that remote learning material was simple enough for students to understand and complete on their own:

Doing remote... I had to pick an outcome that was lower level, because I would not be able to be in person to gauge the understanding of some of my weaker students. So, I had to keep all of the fairly basic ones [LOs]... can you list a name and categorize and things like that. I didn't even keep compare and contrast or critical thinking outcomes towards the end of the unit.... It was very much like almost a correspondence course—can the kid do this completely, independently (P5).

While reiterating time demands and confirming that complex SLOs at the end of units were lost, this teacher exposed other important realities accompanying remote instruction. These included a concern for more vulnerable students who might struggle to learn independently, and an inability to properly assess students to guide further instruction. Moreover, this teacher had little choice but to turn to LOs of lower cognitive value to student learning, while several others described making similar choices. These decisions are likely to have implications for students' development of critical thinking skills and their scientific literacy. Scholars such as Murray (2014) contend that while most students will not become scientists, all students need to think critically to navigate science and technology in their lives, and claims made in the media. I think that learning how to list and categorize versus generating informed decisions on societal issues which other scholars deem compulsory for developing scientific literacy (Maia et al., 2021; Moura, 2025; Osborne & Pimentel, 2022), disadvantages students. Lost opportunities in these

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

foundational grades to develop scientific competencies at the higher end of Bloom's Yet, these teachers made their decisions with the aim that students would learn some of the science SLOs, even if these SLOs lacked the scientific scope of others.

Selecting the least cognitively demanding SLOs to teach during the pandemic allowed some teachers to capture student interest and participation during remote learning—which the Manitoba government had directed them to do (Manitoba News Release, March 31, 2020). One teacher commented on the impact of this approach: “With Weather, just because they were easier outcomes that they could think about and relate to a lot of things that are in the news... I focused mostly on the severe weather, mostly to try and grasp interest” (P9). It was noted that while the entire Weather Dynamics unit and LOs were of nil or lowest priority pre-pandemic, they had increased in priority for this teacher while teaching remotely. Selecting which topics and LOs to use to teach scientific concepts to students remotely was challenging for these teachers, and in some cases, likely limiting for students. Real-world issues like tornadoes, blizzards and hurricanes included in one SLO at the forefront of the Weather Dynamics unit, are unmistakably important and popular topics in the news and of interest to students. However, in my view, while teaching the science of severe weather over complex SLOs such as the final one in this unit: “Discuss potential consequences of climate change” (MET, 2000, p. 4.34), student opportunity to learn the relationship between severe weather and climate change was lost.

While some teachers reduced the depth and breadth of their courses, other teachers continued to teach as much content and as many SLOs as possible during the pandemic. One teacher reflected:

I think you lose the message when you have too much information and the kids would just get lost and overwhelmed. So, I think [if I could go back] I would

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

have started streamlining my lessons earlier, as to keeping it short and sweet and simple (P2).

While considering their content-driven priorities during the pandemic, teachers like this one acknowledged difficulty adjusting instruction in response to students' needs; and that their students would have benefitted from reduced expectations for cognitive achievement—a view that many had described incorporating into their practice. There is general consensus that higher order thinking skills and metacognition are achieved when Cluster 0 Overall Skills and Attitudes SLOs, such as: “Evaluate the reliability, bias and usefulness of information”; “Identify stakeholders and initiate research related to an STSE issue”; “Summarize relevant data and consolidate existing arguments and positions related to an STSE issue” (MET, 2000, pp. 3.10-3.14) are taught (Allchin, 2014; Robertson, 2018). However, based on the interviews I conducted as well as the survey responses I gathered, these aspects were set aside by many teachers during the pandemic if they were considered unattainable or too difficult for students. As “thinking is intricately interwoven with the context of a problem to be solved” (Layton, 1991 p. 65), when authentic complex scientific problems for students to solve were dropped for less complex LOs, such as naming and categorizing, it seems very likely that learning was compromised. Many researchers contend that learning gains in science happen when students have opportunity to engage, explore, explain, elaborate, evaluate, elicit and extend their knowledge to solve complex problems as described in the BSCS 7E science learning cycle (Withers & Schinske, 2016)—and that they are essential to the development of critical thinking and functional scientific literacy (e.g., Suardana et al., 2018; Wang et al., 2020).

As teachers lacked the experience and training necessary for effective remote science instruction and scholars noted that some teachers were not good at this form of instruction

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

(McKnight et al., 2022), I contend that although prioritizing more attainable LOs may have benefitted student engagement and allowed some science learning to occur, doing so does not support the vision of scientific literacy described in the Manitoba science curriculum standards (MET, 2000) or reported in the literature (Allchin, 2014; Calabrese Barton & Tan, 2014; Osborne & Pimentel, 2022).

Preparing Students for Their Next Levels in Science, or for Life and Future Careers. While describing how their priorities for Grades 9 and 10 science had generally endured throughout the pandemic, most of the participant teachers aligned with one who revealed an important underscoring factor to these priorities: “I continue to try to focus on the same most important units as possible, to get through all those important outcomes that they would need for the future” (P10). The interview discourse concerning unit and LO priorities, both prior to and during the pandemic, frequently centered on the teacher’s concerns to teach prerequisites to prepare students for future study in high school or post-secondary education, and in some cases, for their lives and future careers. One teacher framed the priority on prerequisite learning for higher levels that was shared amongst the Grade 9 and 10 teachers:

I always think, what are they going to be exposed to in future high school years?

And if they do end up going to post-secondary, what are some things that they’re going to need for that level of learning, so during the pandemic we focused on physics, biology and chemistry (P3).

The teachers reported overall, and with determined agency, that the three key sciences are important prerequisites to prepare students for the next levels in high school science. Examples of statements expressing this view include: “We prioritize chemistry for Grade 9 because it leads into Grade 10” (P6); “Many of the students may want to go on to take physics and go on to take

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

chemistry in Grade 11. It just makes more sense to do as much as we can with those, so they're well prepared" (P5). While the teachers expressed concern for teaching their students important prerequisite knowledge for future grades—some expressed an awareness of successful entry knowledge from their perspective as teachers of higher grade levels. "Grades 9 and 10 set up the Grade 11 and 12 physics and chemistry... those outcomes are really important to have a solid background on, so I always make sure that we get through those ones in good detail" (P2).

I can relate to these teachers' perspectives from my teaching experience, as student conceptual understandings and skills learned from grade to grade, especially in high school chemistry courses follow a rather narrow continuum, relative to the other high school science disciplines. Grade 9 chemistry students for instance, learn about atomic structure and how elements are organized on the periodic table (MET, 2000); while Grade 10 students use the periodic table to learn why and how elements combine in specific ratios to form compounds (MEY, 2003). Grade 11 science teachers, including myself, know that students require this prerequisite knowledge to successfully learn progressively complex concepts and skills to understand chemical reactions, as expressed in their concern for student preparatory knowledge. As students develop holistically and cognitively, while creating meaning in chemistry through integrating and systematizing ideas as they reflect on prior knowledge (Petersen & Kolb, 2018), many science teachers aim to provide uninterrupted learning opportunities for their students while scaffolding instruction. As such, the Grade 9 and 10 teachers interviewed strongly prioritize teaching chemistry for its prerequisite value to continued chemistry learning, over other priorities, as this teacher explained:

Definitely there would be different priorities. As a department we took a look...

and we picked specific SLOs that were kind of non-negotiable, like foundational

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

for the Grade 9s or Grade 10s, especially in chemistry. We didn't remove any from chemistry, physics or biology, we just prioritized... if all the classes didn't get to the final outcomes [on the department list], it wouldn't hinder the students moving to the next level (P5).

Some teachers directed this conversation to one Grade 9 unit: "The unit that gets the least priority is Electricity, in that it doesn't directly connect with the Grade 10 physics unit" (P3); "The Electricity unit...it's a great unit, but has no connection to any unit in Grade 10 or Grade 11 physics and the concepts don't come up again until Grade 12 physics" (P4).

While prerequisites were found to dominate teacher priorities when making decisions about what to teach their students, some teachers revealed a contrary view, that in at least some units, prioritizing the mathematics or scientific concepts, skills and attitudes to prepare students as scientifically literate citizens was more important. One teacher stated, "Electricity usually tends to be a very abridged unit... I focus more on the things that kids might be exposed to in future physics courses like the mathematics and current electricity, as well as life in general" (P10). This is a view that I share and which I think is supported in the literature. First, learning the mathematics in this unit allows students to identify mathematical relationships between variables, an important Cluster 0 SLO. In Grade 9 science, the relationships between voltage, current and resistance for example are learned through disciplined involvement in abstract reasoning and logic—a notable quality of the nine learning styles described by Petersen and Kolb (2018) and of importance to learning science. However, when asked how important it was to promote these concepts during the pandemic, such as defining voltage in Electricity, when none of the teachers discoursed about this explicit SLO demanding abstract mathematical logic, I inferred that few had taught it. Second, teaching students for "life in general" and for "coping

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

with everyday life, practices, and human needs” is a scripted purpose of foundation C in the curriculum (MET, 2000, p. 9), and from my experience, critical to engaging Grade 9 students in their learning. However, from my experience teaching high school sciences in Grades 9 through 12, I hold a different perspective of this unit’s prerequisite value to learning science that aligns with Manitoba’s Grade 11 chemistry curriculum standards. In that course, the Grade 9 Nature of Electricity is highlighted as a chemistry-related content cluster, rather than a physics-related one (Manitoba Education, Citizenship and Youth, 2006, p. 1.15). Students learn about atomic structure and the behaviour of subatomic particles, particularly electrons in this unit. For this reason, I think that teaching the Electricity unit provides students with important prerequisite understandings to support their learning in the discipline most teachers consider their top priority: Chemistry. Thus, the reduced priority for teaching Electricity reported by many participating teachers for the purpose of teaching prerequisite concepts for continued learning in the three key sciences, might in fact counter their intent.

The direction provided to Manitoba high school science teachers in the Grade 9 science curriculum standards document to “provide students with a proficiency in science that creates opportunities for them to pursue progressively higher levels of study [and] prepare them for science-related occupations” (MET, 2000, p. 2) is also relevant. Whether or not teachers heed this direction to guide their priorities and practice, all the teachers prioritize units and LOs in the three key sciences—chemistry, biology and physics, at all times—often with little or no priority placed on Exploring the Universe in Grade 9 or Weather Dynamics in Grade 10. While firmly established throughout the interviews that teachers teach the units and LOs they believe will best prepare students for the next levels in high school science, for post-secondary education, or for life and their future careers—they indeed provided opportunities for their students as directed by

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the curriculum standards. On the other hand, their robust prioritizing for the three key sciences might deny other learning opportunities for students or reduce the chances that they develop an awareness for vocations in the wide diversity of sciences (MEY, 2003). This is of potential importance to their development of functional scientific literacy, and to their lives.

In Grade 10 science, all the teachers felt that course content priorities to prepare students for subsequent levels in science had resulted in the demoted value of the Weather unit. Examples of statements made expressing this view include: “In Grade 10 we naturally tend to sort of not teach Weather, and so that gives us more opportunities to really dive deep into the three other clusters that will be very important for their electives” (P2); “Weather has been at the bottom [of priorities] because I know that for higher level science courses, those kids need that stuff for moving on (P1)”; and “I don’t prioritize Grade 10 Weather as much, I guess because it doesn’t really have anything that comes after it... and I think the kids do have a lot more day-to-day access to some of that knowledge” (P10). While emphasizing student preparation for future learning as a dominant priority, in consideration of the dated science curriculum documents (MET, 2000; MEY, 2003) and widespread access to digital information, I think that the final point in the latter comment is valid. Increased access to some of the content taught in the Grade 10 Weather unit LOs, such as weather forecasting and storm warning has dramatically changed since 2003, and many students now have immediate access to weather data on their cell phones. Thus, they can observe and interpret dynamic conditions and learn some of the course concepts independently if they are motivated to do so. Irrespective of opportunities for independent learning, the implications of teachers not teaching the fourth units in Grades 9 and 10 science to favour course content perceived more necessary as prerequisite knowledge for future learning, is likely significant. Furthermore, while “It was usually, the odd one out was the one that we never

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

really put much attention into, because they weren't going to see it again" (P3), the pandemic exacerbated this situation:

Astronomy wouldn't be carried on [in Grade 9], and weather wouldn't be carried on [in Grade 10], as a future prerequisite for any course. This had its disadvantages though, because we placed greater emphasis on prerequisites or things that are required for further study in either high school or even university, which kind of eliminated these units and some science in the news... or more practical applications of high school science that they could use throughout their everyday lives (P10).

With a goal to prepare Grade 9 and 10 students for future courses, this teacher explained the perceived cost in their current course—specifically, one-quarter of their course content, relevant news-worthy science, and practical applications of potentially great significance to their students' lives. The implications of lost opportunity to become scientifically versed in the Exploring the Universe or Weather Dynamics units before leaving high school are unknown.

In addition to the elimination of entire units, as pandemic pressures and time constraints had increasing influence on teachers' priorities, choosing prerequisites to prepare students for their next levels of learning also meant the omission of important LOs from their courses:

Chemistry was a priority... we kept all the chemistry outcomes, well actually if any of them we maybe let go a bit of the real-world applications. Unfortunately, I kind of feel like we have to drop these to be able to get through the nitty-gritty pieces that we know as higher-level Bio and Chem teachers...is the stuff they're going to need for after (P2).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Echoing the omission of real-world applications, another teacher added, “I might overlook the practical applications, or...just some history behind the topics or some of the scientists involved, just for the sake of covering the essential outcomes for moving forward” (P5). In making clear that the “nitty-gritty pieces” considered prerequisite outweighed priority for the foundational NOS or for critical real-world applications, teachers became misaligned with the curricular standards and vision for scientific literacy. SLOs with real-world applications in Grade 10 chemistry for example, include the formation and environmental impact of various types of air pollution such as ground-level ozone, airborne particulates and smog; and investigations into technologies that are used to reduce emissions of potential air pollutants (MEY, 2003). These are globally significant SSI requiring classroom implementation and student evaluation (Johnson et al., 2020; Saunders & Rennie, 2011). When chemistry teachers chose to “overlook” teaching complex SLOs with real-world applications, students not only lose out on conceptual understanding of these SLOs, but of foundational GLOs and Cluster 0 Skills and Attitudes SLOs that often accompany these complex SLOs in higher number.

Other teachers provided a contrary perspective however, prioritizing real-world applications from a different Grade 9 unit while also acknowledging its prerequisite value:

In Grade 9, Reproduction is a real-life thing... pregnancy and those types of things are going to be the things that they deal with, so that's a reason to prioritize these outcomes besides just the base layer for Grade 11 and 12 biology (P3).

This teacher explained the need for foundational understandings important to future learning in biology, which from my view are rooted in the concepts of cell division and genetics taught in the Grade 9 course. Moreover, critical real-life applications like pregnancy were recognized,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

which address unit-specific SLOs, GLOs and Cluster 0 SLOs that I see as vital to student acquisition of functional scientific literacy. In my experience teaching the Reproduction unit in Grade 9 science, while teaching LOs centering on human reproductive systems and fetal development were topics of great interest to students; discussions around pregnancy and childbirth, birth control, fertility, abortion, multiple births, birth defects, applications of biotechnologies such as in vitro fertilization (IVF), and discussions addressing current issues captured the interest and attention of most. I recall for example, many students' fascination with a guest speaker from the College of Midwives of Manitoba who brought in a placenta donated by a new mother for students to observe and evaluate. The Manitoba science curricula indicate teachers should provide regular exposure to such experiences of intense involvement, which are optimal opportunities for students to engage in their learning (MET, 2000). Petersen and Kolb (2018) emphasize that learning is enhanced when students are "struck by the strangeness of something unusual, outside of [their] usual experience" (p. 228). Furthermore, when students have opportunity to create meaning through observation and reflection after a concrete experience like this, and to think abstractly, sensitively and responsibly, it may lead to a decision to act with consequent great significance in their lives. As such, when teachers prioritize concrete LOs or prerequisite LOs above more complex SLOs that engage students in learning contexts to confront issues such as fertility or abortion for instance, students are denied the chance to become equipped to address real-world scientific issues and to develop important scientific literacy attitudes and decision-making skills (Sadler, 2011). Furthermore, not only do they deny their students valuable opportunities to develop knowledge, skills and attitudes of value to their lives and careers—but potentially to others. The vision for SL within the Manitoba science curricula encourages pedagogy with an overall goal of "improving the quality of [student's] own

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

lives, and the lives of others” (MET, 2000, pp. 1-2), and “to inform and empower decision making of individuals, communities, and societies as a whole” (MEY, 2003, p. 7). Sjöström and Talanquer (2018) suggest science teachers should enable their students to make informed decisions and express their judgments, interpretations, and arguments through their personal voice in order to humanize science and equip them for action in societal issues—such as fertility or abortion, for instance. Empowered with functional scientific literacy, students might have opportunity to enact Hodson’s vision (1999) which parallels Pedretti and Nazir’s (2011), that science education should enable students to “fight for what is right, good and just” and “work to refashion society along more socially just lines” (p. 617). Significant opportunity for students to become functionally scientifically literate and transformative intellectuals capable of addressing complex social justice issues is written within science curricula (Morales-Doyle, 2017; Tolbert et al., 2016), and teachers have opportunity to serve as the vector.

The realities of pandemic pressures teachers encountered however, restricted such opportunities, and teachers recognized unfolding impacts: “During the pandemic... we ultimately disadvantaged those [students] that didn’t want to continue with science” (P11); and,

For some kids in Grade 11, this is really their first real year of high school, they’re super excited... they’re really buying into what we’re doing, because they recognize, even from last year that they were behind. And they wanted to make sure that they left with what they needed. At least my top kids for sure, in chem (P9).

While exposing an equivalent awareness amongst their chemistry students that the pandemic had impacted their learning, this teacher also intimated that some academically invested students equally value prerequisite knowledge for future science learning. But, as scholars like Murray

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

(2014) contend that most students will not become scientists; and an underscoring aim of the Manitoba senior years curricula is “to develop functional scientific literacy in all Canadian students” (MET, 2021), the comments of participants in this study suggest that some students were indeed disadvantaged by learning opportunities missed when prerequisite content was prioritized.

Difficulties Teaching Some Unit SLOs, GLOs and Cluster 0 SLOs with Restrictions in Place. Joining other factors influencing the content prioritized and taught by teachers during the pandemic, was the constitution of the LOs themselves. Teachers were unable to teach some of the SLOs, GLOs, and Cluster 0 SLOs in the Grades 9 and 10 courses when pandemic restrictions limited student practical work and opportunities for students to collaborate. When asked if their LO priorities had changed during the pandemic, one teacher was also reminded of the intensity of the situation triggering these decisions:

Oh yeah, definitely. I definitely focused on the SLOs versus Cluster 0. On a screen, I couldn't even get kids to ask questions, let alone discuss anything, and pertaining to all the hands-on stuff... I took a lot of that out because it wasn't practical, or in some cases, safe. Oh my gosh...I can't believe *how terrible that was!* (P1).

While reflecting on their professional experiences and emphasizing their LO priorities, this teacher encapsulated what had changed during the pandemic: Engaging science students without practical or collaborative learning opportunities wasn't possible. Others echoed this priority for teaching the SLOs, which was often at the cost of maintaining rigour, and teaching foundational GLOs: “That was the whole driving force, it was concepts first, SLOs, and not the overall general ones. I think it would be too difficult to teach those” (P5). Overall, as teachers continued

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

to teach the LOs they deemed most important, or the ones they deemed possible to teach, their central focus on unit SLOs in the three key sciences was maintained; while their focus on GLOs and Cluster 0 SLOs already of secondary importance before COVID-19, was further reduced.

One teacher indicated: “Obviously some [LOs] get more attention, more hands-on opportunities” (P4), and as teachers planned and implemented science lessons prior to the pandemic, cluster SLOs of a practical nature largely dominated their agenda. But during the pandemic when unable to teach many of these SLOs in meaningful ways without student practical or collaborative work, some were de-emphasized or omitted. A large number of the 67 SLOs in the four Grade 9 science clusters, and 43 SLOs in the four Grade 10 clusters direct students to “investigate”, such as “investigate conditions that illustrate the effects of friction on motion”; “observe” and “collect” as in “observe, collect and analyze class data of single trait inheritance”; “construct” as in “construct electric circuits using schematic diagrams”; “experiment” as in “experiment to classify acids and bases using their characteristic properties,” or “use” as in “use appropriate instruments and units to measure voltage (electrical potential difference), current and resistance (MET, 2000, pp. 1.1-4.33; MEY, 2003, pp. 1.2-4.34). Participating teachers said they struggled to find ways to teach SLOs like these with pandemic restrictions in place. In contrast, cluster SLOs directing students to “define” and “identify” as in “define element and identify symbols of some common elements”; “describe” as in “describe qualitatively how force is related to motion”; “explain” as in “explain how various technologies have extended our ability to explore and understand space”; “differentiate” as in “differentiate between units of measure used for astronomical distances, and perform simple calculations using these units”; “compare and contrast” as in “compare and contrast the function of mitosis to that of meiosis”; “outline” as in “outline factors influencing the Earth’s radiation budget”; “write” as

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in “write formulas and names of binary ionic compounds”; “interpret” as in “interpret graphs of population dynamics”; “analyze” as in “analyze the electrical energy consumption of an electric appliance”; and “discuss” as in “discuss potential consequences of climate change” (MET, 2000, pp. 1.1-4.33; MEY, 2003, pp. 1.2-4.34) were more viable, largely unhindered SLOs and teachers turned their priorities to teaching them during the pandemic. Curricular direction for teaching the equally mandatory cluster-specific SLOs presents great flexibility for teachers to reorganize the SLOs into new groupings and order, and to plan instruction based on student needs, individual contexts, learning resources and other pertinent considerations (MET, 2000). Without debate, Manitoba teachers had never faced greater need to adopt such flexibility, yet without liberty to omit mandatory SLOs, teachers did because practical work wasn't possible. One teacher responded, “The only thing that ended up getting cut...would be more of the labs and the hands-on stuff” (P6). However, “the only thing” meant 16 of 67 Grade 9 SLOs and 11 of 43 Grade 10 SLOs were cut, which unequivocally demand practical work to achieve (MET, 2000, pp. 1.1-4.33; MEY, 2003, pp. 1.1-4.36) and are essential for developing conceptual and procedural knowledge. Moreover, these SLOs that ended up getting cut are linked to multiple GLOs which provide the depth and breadth for developing scientific literacy; and to many Cluster 0 SLOs that broaden the importance of scientific skills and attitudes and NOS processes necessary for students to become scientifically literate (MET, 2000; MEY, 2003).

Although the GLOs and Cluster 0 SLOs are of integral importance to the development of scientific literacy (MET, 2000; MEY, 2003), when asked about their overall LO priorities during the pandemic, the teachers interviewed centered their response around the cluster SLOs and science content. Some teachers pondered carefully over the relative importance of teaching the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

three groups of LOs during the pandemic, and one teacher converged their thoughts to reveal how overwhelming it was to teach all of them:

When it came to a lot of GLOs, some of them weren't easily done, or done at all.

We were struggling to keep our heads above water, so never mind trying to explore some of these things...keep the kids moving forward with the outcomes that were regular SLOs versus the Cluster 0... some of them were just impossible, for me anyway (P2).

Teaching some of the GLOs in Grade 9 and 10 science without practical work just isn't possible. For instance, two GLOs from foundation C of the five foundations, A-E, state: "Students will demonstrate appropriate problem-solving skills when seeking solutions to technological challenges"; and "work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities" (MEY, 2003, p. 12). These LOs elucidate that students are required to do practical work and collaborate with other students to develop important skills to accompany their conceptual knowledge. Further, to assess student procedural knowledge, Manitoba science teachers are directed to observe students in action (MET, 2000, p. 42)—affirming the need for student participation to acquire, and to demonstrate this practical knowledge. Yet, the most notable shift in LO priorities during the pandemic were the result of restrictions to practical and collaborative group work opportunities for students, despite the importance of achieving these LOs. While reflecting on the difficulties of teaching the GLOs and Cluster 0 SLOs without practical work, another teacher compared the relative importance of LOs temporally, claiming, "Before the pandemic the GLOs were just as important as the SLOs. Now I'm finding the GLOs have taken a bit of a back seat" (P4). Considerate of the enormous challenges while teaching Grades 9 and 10 science through pandemic restrictions, it is still

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

concerning that some teachers felt no choice but to assign LOs that are foundational, a demoted rank in their practice. One teacher described the value for GLOs in their teaching during the pandemic:

The GLOs are the connections between all four of the main units that we do, so hugely important. It's so easy as a teacher to focus on the SLOs, but you can't forget that the GLOs are there as well, and that they need to be embraced in every single unit. All four of them (P5).

While capturing the importance of the GLOs and suggesting a perspective that the foundational GLOs are critical LOs for learning science, surprisingly, the teachers did not mention NOS or STSE or their value to SSI and student functional scientific literacy. GLOs found in these first two curricular foundations, A and B, provide great depth and breadth for teaching the authentic nature of science and technology, and for applications to the 21st century scientific problems that society, and students will face. For example, GLOs in NOS include: "Recognize that scientific knowledge is based on evidence, models, and explanations and evolves as new evidence appears and new conceptualizations develop" and "Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations; and GLOs in STSE include "Recognize that scientific and technological endeavors have been and continue to be influenced by human needs and the societal context of the time" and "Identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally" (MET, 2000, pp. 5-9; MEY, 2003, pp. 5-9). These foundational GLOs are linked with SLOs found in the Grade 9 and 10 clusters, and teachers' intentional efforts to teach them are required. In agreement with Leung et al. (2020) however, I inferred from the data that a

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

limited understanding of the relationship between SSI, NOS and content knowledge might underscore the lack of priority for SSI teaching, important to developing scientific literacy. Recently, scholars have reiterated that these elements and their relationship are integral to science education. First, Moura (2025) describes key elements of NOS that should be explicitly taught in school science, one which I consider critical for Grades 9 and 10 students—that scientists work within a sociocultural milieu that is both messy and tentative. Science is culturally and socially embedded (Hodson, 2014; Allchin, 2014; Erduran et al., 2012) and Moura suggests science teachers bear the responsibility to teach their students about NOS and science-society dynamics, to help students develop critical understandings of how the media and politics can use science to shape lives and impact societies. Second, while Osborne and Pimentel (2022) contend that existing curricular standards and formal science education cannot provide students with all the science knowledge that is needed to become “competent outsiders”, to evaluate SSI relevant to their current lives, or to evaluate SSI with science that is yet to come; I believe teachers can better equip their students with foundational skills and knowledge to do so when they select and teach the GLOs through relevant SSI content. One teacher explained how their shift in LO priorities took this turn, “The pandemic served real-time science discussion, for example mRNA and vaccines and current real-life societal issues... I would say decision-making skills, life skills and attitudes became priority” (P6). With media coverage of COVID-19 and global pandemic politics dominating lives and conversations worldwide, in my view authentic NOS and SSI instruction should have arguably been at the forefront of science education throughout this period.

With foundational GLOs at the forefront of scientific literacy development, teachers are expected to underpin instruction in all four clusters and guide all learning activities, practical or

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

otherwise with LOs from these five foundations (MET, 2000; MEY, 2003). Yet, during the pandemic although some considered the value of GLOs in their practice, most did not—and most did not teach the GLOs in all four units because most could not teach all four units. In my perspective, valuable opportunities to teach some GLOs such as ongoing societal and cultural contributions to technological advancements of a global scale might best be found in Exploring the Universe in Grade 9—given international participation in the construction, maintenance and operation of the International Space Station (ISS), and James Webb Space Telescope for example. While in Grade 10, valuable opportunities for students to demonstrate actions that promote a global sustainable environment might best be learned through personal and local efforts associated with pressing SSI such as climate change taught in the Weather Dynamics unit. However, as most teachers in this study indicated that they place little or no priority on teaching these units, the impacts on overall student development of scientific literacy in these grades are likely to be significant—and perhaps more so during the pandemic if GLOs were not held in priority. One teacher considered the potential impacts, stating: “I think in terms of the GLOs during the pandemic, I think the students have lost a lot” (P5). I would say they also lost out when it came to the Cluster 0 SLOs.

Despite explicit direction in the curricula to integrate the Cluster 0 Skills and Attitudes SLOs into each of the four clusters (MET, 2000), most teachers in this study generally assigned low priority to teaching them. When asked if their LO priorities include the Cluster 0 SLOs, two teachers' responses seemed to indicate a vague awareness of this cluster: “That’s it, Cluster 0, that’s the term I was looking for” (P6); and “I would say I’ve got to be honest, I’m not fully familiar with the Cluster 0” (P4). I considered that perhaps a lack of awareness, or discomfort with a lack of awareness helped explain how Cluster 0 SLOs were quickly dismissed during

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

interview discourse, and of low priority for some teachers. In my experience teaching Grades 9 and 10 sciences, Cluster 0 Skills and Attitudes SLOs are commonly considered peripheral—if considered, while unit SLOs are usually of foremost priority for teachers. Of potential relevance to the priority, or lack thereof, that teachers place on teaching Cluster 0 SLOs; when I was a member of the Manitoba Grade 11 Biology curriculum development team, I do not recall any dialogue associated with Cluster 0 SLOs, or GLOs in our meetings—only unit SLOs. Despite holding priority placement and importance over the unit SLOs, the foundational GLOs and Cluster 0 Skills and Attitudes SLOs are distinctly separated from the rest of the science curriculum standards documents in their layout. This might lead teachers to bypass both of these elements as they search for content SLOs to teach within the four clusters. Furthermore, identifying critical SLOs as Cluster “0” might fail to suggest importance, as do page numbers appearing as ‘unworthy fractions of a page’: as 0.3 for example (MET, 2000, p. 0.3; MEY, 2003, p. 0.3).

While some teachers expressed a generally limited awareness of Cluster 0, others seemed to see the SLOs in this cluster as lacking substance to teach directly, or that they might be learned through instruction of unit SLOs. One teacher expressing this general view offered:

It's certainly nothing I ever blatantly say, like hey we're going to learn the Cluster 0 curriculum kind of thing, um, it's just part of my practice. I just try to embody it and represent it and model it for the kids, and hopefully they pick up on a portion of that (P2).

As the Cluster 0 Overall Skills and Attitudes SLOs emphasize the importance of scientific skills and attitudes to learning science, and the essential processes and NOS that students require to develop functional scientific literacy (MET, 2000; MEY, 2003), if teachers don't decisively

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

teach these LOs and “hope” their students will pick them up, it seems highly likely that learning is compromised.

Some teachers acknowledged Cluster 0's presence in their usual teaching however, stating: “Absolutely. Cluster 0...if you're doing inquiry and experimentation, all of those Cluster 0 pieces come up” (P11); “Lots of my colleagues don't place any emphasis on the scientific method or lab safety, and I add that in” (P9); and:

Prior to the pandemic I had my kids doing labs, or... investigations working with materials. I like to do a lot of those soft skills, those Cluster 0: Do you know how to handle equipment? Do you know how to be safe? Do you know how to ask questions? Do you know how to work apparatus? (P1).

While some of the teachers expressed their awareness of lab skills and safety included in Cluster 0, others had a vague awareness of Cluster 0 and the 48 SLOs in the cluster. I worry that if teachers maintain a vague awareness of their complexity, translating the critical concepts in these SLOs into effective instruction might be problematic. While teachers indicated they did not pay much attention to these LOs prior to the pandemic, they explained that their pandemic struggles exacerbated this situation.

During the pandemic, teachers omitted specific Cluster 0 SLOs because they were associated with practical activities and organized labs that students could not do, explaining: “Within Cluster 0 with the hands-on stuff I just skipped a lot of that so I wasn't dangling a carrot there without a reward at the end” (P5); and:

They definitely decreased in value because we couldn't do some of it... I'm not going to go into a ton of detail on equipment skills and lab safety when you

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

can't work in a lab, right? It didn't make a whole lot of sense and I felt like that was going to be a bit of a tease for them (P1).

Restrictions to practical learning halted teachers from doing any introductory skill-building lab work found in the Cluster 0 SLOs that might be required for students to safely and proficiently participate in successive practical work. This closed the door for teaching other LOs important to promoting scientific literacy, including other Cluster 0 SLOs such as "Identify further problems and questions arising from an investigation" (MET, 2000, p. 3.12).

Among the nine groups of Cluster 0 SLOs totaling 48 skills and attitudes SLOs in Grades 9 and 10 science, many require authentic practical work to achieve, including SLOs such as: "carry out procedures that comprise a fair test"; and "work co-operatively with group members to carry out a plan, and troubleshoot problems as they arise" (MET, 2000, pp. 3.10-3.14).

Attitude-based Cluster 0 SLOs such as: "Demonstrate work habits that ensure personal safety, the safety of others, as well as consideration for the environment", and "demonstrate confidence in the ability to carry out investigations in science and to address STSE issues" (pp. 3.10-3.14) also require practical work to achieve. Understandably, when unable to utilize practical work to teach science during the pandemic, SLOs like these were not taught. However, many other Cluster 0 SLOs that are attainable without practical work include: "Propose questions to be tested experimentally"; "state a testable hypothesis or prediction based on background data or on observed events"; "determine criteria for the evaluation of an STSE decision"; "interpret relevant WHMIS regulations"; "select the best option and determine a course of action to implement an STSE"; "discuss social, economic, and environmental effects of past and present scientific and technological endeavors"; "appreciate and respect that science and technology have evolved from different views, held by women and men from a variety of societies and cultural

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

backgrounds”; and “express interest in a broad scope of science- and technology-related fields and issues”. Yet, the teachers interviewed indicated they did not prioritize the Cluster 0 SLOs in their teaching during the pandemic.

During the dialogue with teachers regarding the Cluster 0 SLOs, it was interesting to note they did not make reference to NOS or STSE skills and attitudes, or decision-making. As scholars like Allchin (2014) report the importance of NOS to support functional scientific literacy is recognized internationally; and Shanahan and Bechtel (2019) contend that engaging students in STSE conversations allows them to develop a context while learning science that they propose can be life changing, I see teaching Cluster 0 SLOs aligned with NOS and STSE for student scientific literacy as very important.

Overall, the 28 GLOs and 48 Cluster 0 SLOs (MET, 2000; MEY, 2003) guiding Grades 9 and 10 teachers embrace an extensive amount of scientific conceptual knowledge, skills and attitudes. If these are not taught with purpose or assessed, impacts on student scientific literacy are likely to result (MET, 2000; MEY, 2003). Teachers acknowledged potential impacts on student development of procedural knowledge, skills, and associated conceptual understandings when unable to teach science with practical work during the pandemic. With the loss of practical work, scientific and technological attitudes were difficult to foster or to assess during periods of remote learning and when teachers could not observe their students participating in co-operative learning activities or discussion (MEY, 2003). Without such opportunities to appropriately assess students, whether or not Grades 9 and 10 students acquired important scientific attitudes found in many of the Cluster 0 SLOs during the pandemic is largely unknown. I concur with one teacher's perspective that “The broader GLOs and scientific attitudes and skills [Cluster 0] are really what encapsulate the love of science, and being able to apply those elsewhere” (P5), but with

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

restrictions to practical learning in place during the pandemic, most of the teachers were unable to facilitate opportunities to teach these LOs. While the teachers revealed an overall priority for unit SLOs both prior to and during the pandemic; most indicated greater awareness and priority for GLOs in their usual practice over Cluster 0 SLOs. The pandemic seems to have had a variable influence on the former and may have had a dire impact on the latter. Overall, with comprehensive development of scientific literacy competencies dependent upon all of the curricular LOs being taught in each grade, the teachers revealed this was even less possible during the pandemic than it was before it began. Consequential impacts for student scientific literacy were expected, which likely differed considerably for students across the province.

School or Team Decisions about Curricula, Instruction and Common Exams. The interview data suggest that Manitoba teachers have variable autonomy over what they teach in Grades 9 and 10 science at any time. Some participants explained that direction from their administration and teaching teams limited their freedom to operationalize their unit and LO priorities: "I have to focus on what is going to be on our common exam" (P3). The arrival of the pandemic, according to another, brought common exams and greater administrative control over what they could teach: "With common exams now we all have to do very specific things" (P5). An overall approach in another school made it clear that while some teachers' priorities were firmly set within school course structures which included common exams, individual teachers like this one still had some flexibility to set teaching priorities: "We have a common exam at our school, so [in Grade 9] everybody does Atoms and Elements, and everybody does Reproduction, and then most will do some Electricity" (P6). It also became clear that administrative or team decisions, particularly during the pandemic, might override those of individual teachers, and limit some from teaching all four clusters, or all the SLOs in the Grades 9 or 10 science courses

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in schools where common exams are given. Another teacher explained, “We have a common exam in Grade 10, so we all have to do Chemistry, In Motion, and some ecology” (P1). While noting a complete disregard of the fourth unit in Grade 10, Weather Dynamics, these interviews suggest that school and team priorities to implement common exams often override the priorities of individual Grades 9 and 10 teachers, and may impact their ability to teach their students the entirety of the curriculum standards (MET, 2000; MEY, 2003).

Safety Issues for Students and Staff. With health and safety of students and staff of foremost priority in Manitoba schools throughout the COVID-19 pandemic, teachers experienced a dramatic shift in their usual practices to meet crucial health and safety protocols as directed by their school divisions. Although these Grades 9 and 10 teachers attempted to maintain unit and LO priorities in place pre-pandemic, general pandemic protocols such as social distancing, sanitizing, and wearing masks impacted their usual content priorities for SLOs promoting collaborative student work; and SLOs best taught through laboratory or hands-on practical work. School divisions, schools and teachers set different operational guidelines during the pandemic in conjunction with other priorities. This was something that I experienced and that one of the participating teachers explained:

The administration prioritized having the science labs available for Grade 12 students...so that anyone who was going on to university would still get to do hands-on stuff. So, if I wanted to do anything with my Grade 9s or 10s, I would have to transport everything to a different area of the school. There were also some safety concerns as far as using chemicals and whatnot, and I was not comfortable without being in the lab, without the proper precautionary equipment (P3).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Complicated changes within schools brought increased difficulty for teachers as they were required to adapt their teaching spaces along with their pedagogy, safely—and participating teachers explained that valuable learning opportunities to foster scientific literacy competencies were consequently cut. One teacher stated, “I had to replace labs... but that was due to the limitations of the equipment itself, and class size, like in the class space itself” (P10), referring to the limitations of physical space afforded each student while physical distancing was enforced. Other teachers explained: “With desks six feet apart, plexiglass partitions and students wearing masks, labs turned into discussions” (P2); “Anything that might have been partners or group work or anything like that I had to take out because for so much of the time it was two-meter distancing” (P5). Many GLOs, SLOs and Cluster 0 SLOs requiring student co-operative work were limited by pandemic safety restrictions, and teachers did their best to adjust learning activities creatively, resourcefully, and safely. One teacher determined to have students do some form of practical work to learn concepts in the Grade 10 In Motion unit described:

We were going to do something on velocity, normally we have a ramp... but I had to come up with something else. I found these little cars in the back... they can experiment with these and test their velocity... they were able to work on that safely in the hallway space allowed (P3).

Although teachers adapted whenever possible to provide safe learning spaces and experiences for their students, practical learning activities best suited to teach many Grades 9 and 10 LOs were unavailable. Furthermore, one teacher added:

During the pandemic, how do you spread out all these supplies for kids? I didn't have enough for them... so there were times you would maybe have half the class do like a hands-on kind of thing, and then wipe everything down, and then

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

two days later the other half could do it. But it became problematic. If kids were absent, it just became a real hassle, so I guess [practical activities were utilized] very, very infrequently during the pandemic (P1).

With safety their top priority, attempts to implement any form of practical work to learn science were time consuming and fraught with other issues as this teacher pointed out, and consequently seldom used.

As these Grade 9 and 10 teachers adjusted what they taught and how they taught science during the pandemic while observing school safety agendas and guidelines, while collaborative and practical learning activities were restricted, these teachers were unable to teach many important concepts, skills and attitudes vital to student scientific literacy development in these grades. Yet, in consideration of the aim for students to develop Overall Skills and Attitudes including: “Demonstrate work habits that ensure personal safety, the safety of others, as well as consideration for the environment”; and “Discuss safety procedures to follow given situations”; although through different contexts than intended by the curricula (e.g. acid and base spills)—safety habits and procedures learned to protect students and staff from the immediate and authentic threat of the SARS-CoV-2 virus throughout a two-year period likely superseded other avenues to teach these Cluster 0 SLOs.

Curriculum. As the Manitoba science curriculum documents provide the scientific and technological concepts, skills and attitudes for teaching Grades 9 and 10 science, they would be expected to be of foremost value, and influence on teacher priorities. However, teachers' comments regarding a perceived lack of curricular support to effectively promote a form of functional scientific literacy in line with the challenges of the 21st century as envisaged by scholars like Valladares (2021), where “students seek the best-informed solutions to complex

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

social, cultural, political and environmental issues” (p. 566) surfaced. The world is changing so quickly, and science educators need the best foundational tools to teach their students. As such, the participants shared their perspective on how perceived deficits in the Manitoba science curriculum documents affect what they teach their students.

Individual interpretations of the science curriculum documents significantly influenced some of the participating teachers' practice. According to this teacher:

The curriculums need to be updated. I think they're from the seventies, they're very outdated. They need an overhaul with what the focus should be... there was absolutely no way to get through it... it's really hard to provide any sort of hands-on experiential opportunity... and cover everything (P1).

Although the Grades 9 and 10 documents were published in 2000 and 2003 and not in the 1970s, all of the teachers I interviewed noted that updating is required. One teacher pointed out, “I still cover a lot of outcomes, but the curriculum is *super dated*... it's *so old*” (P3), explaining difficulties with interpreting SLOs with outdated language and sociocultural views, but moreover that outdated links and lack of resources to craft suitable learning activities are a concern.

Another teacher with many years of experience teaching Grades 9 and 10 science and school administrator experience added: “Our curriculum documents for Grades 9 and 10 are so old and out of date, and out of touch with practices... as a result, anybody new would have struggled with some of that for sure” (P2). While experienced teachers are poised to bring long-term understandings of their curriculum into their evolving practice, I share the perspective that newer teachers might be in a particularly difficult position to navigate the large clusters and extensive lists of LOs described in dated curricula. This may have been problematic for teachers new to Grades 9 and 10 science instruction during the pandemic. Additionally, all the teachers

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

interviewed emphatically shared this teacher's perspective that the Grade 9 science curriculum document (MET, 2000) and Grade 10 science curriculum document (MEY, 2003) are out of touch with practices and require critical updates. I agree, and from my recent experience as a practicum advisor and as a university instructor working with teacher candidates, I also observed that pre-service teachers struggle with direction provided in the "Notes for Instruction and Student Learning Activities" sections of the curriculum standards documents developed more than two decades ago—prior to the extensive accessibility of the Internet as a transformative teaching tool and resource. I think that other updates to descriptive context, such as "Students may have familiarity with the potential consequences of climate change" (MEY, 2003, p. 4.32); to language, such as "word processing" (MET, 2000, p. 1.38); and to examples and references to enhance the overall value for science learning would additionally benefit all 21st century teachers and students. Many teacher candidates I have worked with described a general awareness that neighbouring provinces had more recent updates to their science curricula and questioned when new curricula might be expected in Manitoba, while they invested deeply into learning how to teach science content they might eventually be teaching. Furthermore, and of great significance to this study, when Grades 9 and 10 general science teachers needed immediate access to science education websites and online learning activities in March 2020 to teach the four clusters and their LOs remotely, these resources could not be found in the curriculum standards documents.

The teachers I interviewed also expressed the view that the science curricula require revision with consideration to student learning modes and styles and the inclusion of important LOs designed to promote critical thinking to advance student scientific literacy in the 21st century. One articulated:

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

I started teaching Grade 9 science in 2000, and that's when the curriculum was updated. So, we are in dire need of an updated curriculum, but an applicable update to curriculum, I think, is important, considering the type of learners that we have now. But I still think that it's important to have GLOs and SLOs that promote scientific literacy...we want to have literate and capable students, and not just that they know things, but they know how to apply things and can make connections, and they are critical thinkers with soft skills as well. That's really important (P5).

I see this teacher's view of effective curriculum as capturing all elements of functional scientific literacy as described in the scholarship (e.g., Lederman et al., 2014; Maia et al., 2021; Natale et al., 2021). Their comment is telltale to the direction teachers require for what and how to teach, in order to collectively incorporate relevant SSI and agendas of today's world into science instruction with consideration of students' diverse learning modes and styles. In further consideration of students' best interests, one teacher suggested an extreme overhaul to the Grades 9 and 10 curricula:

The curriculum documents need to be revised, rebuilt entirely from scratch. Just reducing the overall expectations would be, I think, of much more benefit to students, especially if we're trying to reframe school in the sense that we're preparing them for adult life, as opposed to preparing them for post-secondary education (P10).

This teacher's view that science education should prepare students with scientific concepts, skills and attitudes for life versus higher levels of science education, aligns with the view of some scholars (e.g., Maia et al., 2021; Erduran et al., 2012), and with the Manitoba curricular

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

framework (MET, 2021). Further, while revealing their belief about what is most important for Grade 9 and 10 science learners, this teacher's suggestion that the curricular expectations are perhaps too great was voiced by most, and summed up by another teacher who stated, "I've reduced my [curricular] expectations of students during the pandemic, and they would be overwhelmed if I didn't" (P9). While acknowledging the need to adjust their curricular content and approach throughout the pandemic learning environment, the overall perspective provided by the teachers was that the dated curricular documents were not as helpful to them during the pandemic as they should have been and this significantly impacted what they taught their students.

In summary, the curricular units and LOs Manitoba Grades 9 and 10 science teachers prioritize changed in response to a number of factors that influenced their practice throughout the COVID-19 pandemic. Although remaining grounded in their best efforts to care professionally for their students and to advance scientific literacy, these teachers described their experience teaching the curricular LOs without the practical work they value as essential, as a challenging ordeal. In the next section, I explore this theme and provide evidence from the interview data.

Theme Four: Practical learning experiences were valued by these teachers to advance student scientific literacy—and teaching Grades 9 and 10 science without them during the COVID-19 pandemic was exceptionally challenging.

Most of the teachers replied passionately when asked about the value of practical work for teaching Grades 9 and 10 science with remarks like, "*Huge!* The most important piece of it all, I think" (P1), aligning with science education scholars who stress that hands-on practical experiences are a required part of instructional activities in science (e.g., Adedoyin & Soykan, 2020). Further, as developing scientific literacy demands practical and transferable skills and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

scientific attitudes acquired in a well-structured and intellectually stimulating lab program (Kyne & Thompson, 2020) and are crucial for students to develop their scientific identity (Campbell et al., 2020); these science teachers valued opportunities to implement practical learning for their Grades 9 and 10 students whenever possible. Research reporting the importance of practical work to develop conceptual understandings in science; to develop scientific procedural skills and attitudes; to augment collaborative and metacognitive skills; and to build student confidence through frequent applications to real-world scenarios dominate the science education literature on practical learning and are vital to analyzing this research. During the interviews with these teachers, I appreciated the value in the practical activities they implemented, which helped me to draw a more precise picture of how pedagogy in these courses changed during the pandemic, and the impacts that restrictions to practical work had on student development of scientific literacy. The participant teachers were clear that although teaching practices and priorities changed during COVID-19, the value they place on practical work for teaching students in Grades 9 and 10 science did not.

The teachers divulged their deep-rooted values for practical activities to teach science through routine use of these activities in their Grades 9 and 10 practice, and from my perspective it is difficult to conceive of ways that students might learn science without them. When asked how often they engaged Grade 9 and 10 students in practical work before the pandemic, the teachers replied: "Pretty often... I'm not going to say daily, but probably two to three times a week the kids are doing something like practical group work... or a lab" (P8); "Probably a couple of times a week, I was a pretty hands-on person to begin with" (P6); and

I try to at least do some form of physical hands-on activity at least once a week, if not twice, as an opportunity for them to first off, get out of their seats and do

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

something, but also to embrace the laboratory science aspect of science itself (P4).

All the teachers agreed upon the importance of regular opportunity to for students to engage in practical work. I see this as reflecting Dewey's perspective noted earlier, that "understanding by its very nature, is related to action" (Layton, 1991, p. 43), and supported by 5E and 7E science learning models. These teachers value practical work for students to develop science understanding in association with the broad range of curricular LOs; and take direction from their curriculum documents which suggest students should learn science through concrete and contextual learning processes that include scientific inquiry, technological problem solving, and decision making (MET, 2000; MEY, 2003).

Some teachers qualified their quantitative answers and explained their reasoning behind how often they engaged students in practical work; others identified the importance of practical work for teaching specific clusters; and some provided detailed examples of practical work employed in their regular instruction of Grades 9 and 10 science. Although some teachers said they had too many practical activities to list, one excitedly shared a few they routinely incorporated into their Grade 9 and Grade 10 courses:

Oh yeah, we have the unrestrained passenger lab; we have snap circuit kits to do electricity; we do station activities for static electricity; we have a planaria lab where they learn asexual reproduction; we have a lily lab where we look at sexual reproduction and all parts of the flower; and we figure out using microscopes, all the stages of mitosis, and there's just *tons of stuff*! There's just not enough time, right? (P1).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The routine practice of varied experiential instruction in science that allows students to engage, explore, explain, elaborate and evaluate (Withers & Schinske, 2016) is of clear value to this teacher, and all of the teachers I interviewed. While voicing their poignant final point that practical activities require considerable time to facilitate in addition to the substantial planning and equipment required, this teacher's underscoring value for their benefit to teaching authentic science was heard. Another teacher added:

I think the practical aspects of science are *very* important. For example, there are practical aspects of naming compounds and formulas in Grade 10, such as when they're reading ingredients for shampoo bottles, or when they're reading ingredients on food items, knowing what's in it, and what they're consuming... we need emphasis on the practical aspects of every topic that they're learning and why they're learning it, what use is it to them now, and in the future.

From personal experience, teaching Grade 10 students about the toxicity of microplastics found in shampoo, personal care items or packaging for instance, and global microplastic contamination is expedited by hands-on opportunities to explore consumer products, which scholars suggest is supportive of deep conceptual understanding (Cheng et al., 2021; Singal et al., 2021). Furthermore, handling, exploring and testing items like this used in daily life allows students occasion to develop functional scientific literacy as they learn foundational GLOs including: "Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life" (MET, 2000, p. 14). Such experiential learning is of critical importance in preparing a scientifically literate citizenry, and these Manitoba science teachers highly value its necessity for Grades 9 and 10 students to learn science. As one teacher stressed "Students need to know how to be inquisitive, because *that's what science really is...* to be

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

curious... and explore things as scientists” (P4). When students have opportunity to practice thinking and acting like scientists (Layton, 1991), these authentic practices allow them to develop procedural skills fundamental to scientific inquiry, and to acquire scientific attitudes such as curiosity, skepticism, accuracy and precision that prepare students to responsibly apply their scientific knowledge and skills (MEY, 2003). When teaching Grades 9 and 10 students with a practical approach, I observed students develop scientific skills together with attitudes in a mutually reinforcing way. When students have opportunity to engage in practical work and develop skills to ask scientific questions such as predicting the outcome of an experiment for example, dispositions including curiosity and creativity are fostered, which in turn, motivate further practical experiences.

Teachers emphasized: “Hands-on is so important, you can’t replicate it with a diagram” (P10); “They’ll *always* remember what they do and see” (P11). These teachers align with other educators globally and know there is no replacement for hands-on learning opportunities (Hong et al., 2018; Kelley, 2020). This finding supports the prominence of “experiencing” as both a mode and style of learning as described by Petersen and Kolb (2018) and suggests an elevated status for experiential learning, valued by the participant science teachers, myself, and science education scholars (e.g., Gya and Bjune, 2021).

Aforementioned, the value of practical work for learning science is well established in the post-secondary science education literature, and contributions found in biology fields might support the value of practical work to learn biology in high school science, such as in the Reproduction unit in Grade 9 science. When Grade 9 science students learn about various types of asexual and sexual reproduction in plant and animal species and investigate anatomical adaptations which enhance reproductive success (MEY, 2003), I know first-hand that the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

conceptual understandings, skills and attitudes students develop when dissecting a flower for instance, would be very difficult to teach through other means. Moreover, without new experiences, such as dissecting a flower, there can be no “real learning” according to Petersen and Kolb (2018)— “people only recombine and reiterate what they already know” (p. 228).

Empirical studies from the post-secondary fields of chemistry and physics are more pronounced than those found in biology, and Grades 9 and 10 teachers described being extensively reliant on practical work to teach these disciplines. Several teachers stressed the regular inclusion of lab work within their chemistry and physics units: “A minimum of once or twice a week, whether building circuits or doing chem experiments” (P7); “Definitely about once a week. Often in Grade 10 Motion, as well as the Electricity unit in Grade 9” (P8); and “We did a ton in Grade 10 physics and in chemistry, a lab every couple of weeks (P3)” —this routine facility of lab work in chemistry and physics identified in the teachers’ standard practice harmonized with my practice in Grades 9 and 10 science prior to the pandemic. While reflecting on the frequency of practical work in their classes, one Grade 9 teacher openly expressed their regret with not providing students practical learning opportunities in all units: “To be honest not as often as I should have. It depended on the unit. Electricity was about 80% hands-on though” (P6). Another teacher echoed the value of practical work in this particular unit:

The Electricity unit... it’s hard for students with a lot of math and equation manipulation. Yet, we are going to have electricians in the classroom, so they need these skills, right? It’s probably the most hands-on unit of all of them in Grade 9 science...if you want to engage kids, you can collect those kinesthetic learners by doing the electricity unit right (P4).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

I agree with this teacher on four counts. First, the concepts of voltage, resistance and power are, from my experience, difficult scientific concepts for students to learn without practical work, and some struggle with the associated mathematical calculations. Simple investigations and observations when building circuits with batteries, wire and lightbulbs for instance, allow students opportunity to explore the mathematical relationships between these variables. Second, as the teachers had previously pointed out in discussions around LO priorities, significant opportunities for hands-on learning are indeed found within this cluster while students investigate and construct to learn about electrostatics and current electricity. Lastly, students should have opportunity to learn all skills prescribed in the curriculum through meaningful hands-on practice whenever possible; and although teachers may or may not focus on teaching science for specific professions, students' functional scientific literacy and future options may be dependent upon it given their career choices. Furthermore, scientific literacy is enhanced when Grades 9 and 10 students engage in kinesthetic activities and learn experientially (MEY, 2003). As the teachers reported: "The hands-on stuff is more fun for the kids. They're more interested when they are actually *doing something*" (P9); and "I think Grade 9s and 10s especially, prefer learning with hands-on materials" (P6). Their views align with the Manitoba science curriculum that states "students appreciate the hands-on experience of doing science" (MEY, 2003, p. 40), and with my experiences teaching Grades 9 and 10 science. As such, I appreciate the approach one teacher described:

I do between 14 and 18 labs and activities in order to make science relevant and enriching... I have a variety of activities that take the whole class, or multiple classes, or they're just a short thing... I do *a lot* (P1).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

As previously discussed, context-driven, relevant student-centered activities valued by this teacher and others help prop meaningful science learning. During the pandemic however, teachers were challenged to teach science and promote scientific literacy without the practical work they highly value to do so. As one teacher explained: “It was a very stark contrast between learning through engagement and activity versus lecture hall or theater style learning, which obviously, with Grade 9s and 10s, is not a very conducive environment to their learning” (P10). As the suspension of traditional educational activities crippled science educators globally (Hothi et al., 2022), my data suggests that this stark contrast was felt in many Manitoba science classrooms as teachers were restricted in teaching science through practical, hands-on learning activities. This absence was profoundly emphasized by the teachers, and one boldly announced, “Laboratories or hands-on learning activities, *gone*” (P9)—a genuinely inconceivable thought for experienced science teachers including myself. Others offered, “During the pandemic, especially at the beginning stages, social distancing was enforced so lab work was non-existent” (P11); and “Hands on things *definitely* went to the wayside” (P7). Science teachers were in a particularly tough situation given the practical nature of this discipline, and necessity to shift experiential instruction to virtual platforms (Babinčáková & Bernard, 2020; Kelley, 2020). Finding virtual opportunities for students to be inquisitive, and to explore or apply their scientific knowledge and skills throughout the pandemic challenged these Manitoba teachers along with educators globally—yet these approaches are vital for developing scientific literacy. While the prevailing science education scholarship is clear that practical activities are critical for the development of scientific literacy competencies and cannot be replaced, and lockdowns and restrictions during the COVID-19 pandemic meant this type of instruction wasn’t possible, teachers were faced with a pedagogical paradox.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Teachers experienced great worry and frustration that they could not provide their students with the mandatory experiences they value, to learn science. “Like *try* to teach somebody how to drive a car without *actually* getting them into the front seat!” (P1) was how one teacher portrayed the enormity of the challenge of teaching science to their students without hands-on learning opportunities. Another teacher analogized from their coaching perspective: “If my basketball team couldn’t practice, it would be pretty impossible to learn the game” (P6). Other teachers elaborated: “My classroom is pretty hands on... [and went] from learning stations and demos, to pen and paper” (P9); “With 2 metres of distancing, we weren’t able to do *any* laboratories” (P3); “With desks six feet apart... labs turned into discussions and students just didn’t tune in. They weren’t having as much fun learning the content” (P6); “Because we weren’t doing the practical side of it... within kids, it killed some of that natural curiosity” (P7). Although equipped with pedagogical skills and expertise for in-class teaching, the demanding modes of remote and hybrid instruction that teachers were not trained for, proved significantly challenging (Meng et al., 2020; Rossettini et al., 2021), particularly when it came to practical work. Moreover, as these teachers grappled with the absence of joy, excitement, and anticipation that had previously fuelled science learning and filled their classrooms, I could relate to their experiences when teaching during the pandemic, and their feelings of loss for their students. While one teacher explained the general view shared by teachers during the interviews, “It was just the laboratories themselves. That was the part that I was finding either very hard, or not possible to adapt, once the pandemic began” (P4), I felt a sense of grieving in their voice. Some teachers elaborated on the extreme change in their teaching: “Overall I provided less than a third of my usual labs, and furthermore, labs were individualized at students’ desks and reduced to very simple mixing and observing or counting procedures without any collaboration, the level of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

analysis was much less" (P5); "Students couldn't do labs and they seemed more... not just isolated physically, but isolated in their learning" (P11); and "The content was coming from me to each student. It wasn't going from student to student, or them discovering on their own. That's what changed" (P1). As noted earlier, the pursuit of scientific literacy is "not something that the teacher does alone, but rather something that students learn to do..., and practice..., within their own social context" (Feinstein, 2011, p. 180). As such, it wasn't surprising that Grade 9 and 10 science teachers struggled to teach some scientific concepts in meaningful ways, when practical and collaborative work were restricted during the pandemic.

The Manitoba science curriculum documents prescribe foundations for scientific literacy that include LOs that students are expected to know but also prescribe LOs that students are expected to be able to do as a result of their senior years science education (MET, 2000); and in order for instructional environments to be effective, students require opportunities to work cooperatively with other students, to initiate investigations, and to communicate their findings (MET, 2001). One teacher pointed out, "When they do the hands-on that not only allows them to actually see it for themselves and to experience it for themselves, but also to work with other students" (P5). As teaching scientific concepts and procedures in high school sciences is routinely achieved through student group or partner work, collaborative skills and attitudes important to scientific literacy development are often learned in partnership with practical work.

In my experience, teachers commonly place student-centered learning at the core of their Grades 9 and 10 science courses, and given the importance of collaborative student learning, school laboratories are commonly designed in support with equipment and supplies grouped in stations. Furthermore, some of the Grades 9 and 10 cluster SLOs explicitly indicate that students need to do practical work in collaboration with other students, such as "observe, collect, and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

analyze class data of single trait inheritance” (MEY, 2000, p. 3.17). Additionally, from my perspective, at least 10 of the 28 foundational GLOs such as “employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data” (MET, 2000, p. 13; MEY, 2003, p. 12); and at least half of the 48 Overall Skills and Attitudes Cluster 0 SLOs, including “carry out procedures that comprise a fair test”, and “identify and suggest explanations for discrepancies in data” (MET, 2000, pp. 0.3-0.7; MEY, 2003, pp. 0.3-0.7) are either directly learned through student collaborative work, or best learned through student interaction and discussion. But with limited opportunity for students to work cooperatively with classmates in lab work or to assume group roles and responsibilities during the pandemic, some GLOs and Cluster 0 SLOs were extremely difficult to address. The teachers articulated the loss of cooperative learning they value for teaching science: “Yeah, I probably dropped, in terms of collaborative work or lab type work, it was probably down *seventy-five percent* of what I normally do” (P2). Another teacher emphasized the impact of this loss,

I think one of the greatest opportunities that science presents, is a lot of collaborative work where kids can work in lab groups, and they can discuss concepts, theories, and then apply them to a real-life situation... before the pandemic we saw a lot of those benefits. And then, of course, during the pandemic you're told no, you cannot do any of that, or you're limited on who you are able to work with, and you're at a distance (P1).

Although these teachers valued and relied on regular opportunity to advance student knowledge and metacognition fostered through collaborative discussion between students while doing science prior to the pandemic; aligned with many scholars (e.g. Garcia-Vedrenne et al., 2020),

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

their frustrations resonated throughout the interviews that effective alternative science pedagogy does not exist.

While teachers adjusted their instruction to meet safety protocols throughout the changing pandemic periods, the omission of practical and collaborative learning activities during remote instruction meant the loss of some LOs important to promote scientific literacy.

However, during periods of BL when teachers taught some students in class while some remained in their home for the lesson, although limited by pandemic safety protocols greater opportunity for practical and collaborative learning presented itself. Without question, the participant science teachers and myself choose to teach science through an authentic practical and student-cooperative approach because we value its necessity for learning science, struggle to teach science by different means, and seized any opportunity available. This determination was conveyed in one teacher's response:

In class, it was a lot of hands-on stuff. *Anything* that we could do hands-on, that I knew we could not do online, that's what we did in class. It was a little bit more intense when they were in on those days... because we were trying to pack in a lot (P9).

Although teachers could not teach some of the Grades 9 and 10 scientific competencies remotely, this teacher's value for hands-on learning was clear, aligning with Kelley's (2020) view that hands-on practical work should take place in the classroom and be prioritized in all BL situations. As Kelley had pointed out, during periods of in-person instruction, social distancing and other safety restrictions also limited 'normal' collaborative lab work, as one teacher described:

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

When we had restrictions, any type of group work, any type of jigsaw method, any type of collaboration or connecting, hands-on stuff like the labs were really tricky, because I spread them out so kids were working by themselves. How to learn together was removed (P5).

Yet, learning together through collaboration and communication are key elements of 21st century scientific literacy (Valladares, 2021), rendering a science education void of interaction with other students while learning in isolation, unsuitable.

Regardless of the pandemic period, these teachers overall concur with the scholarly view that laboratory experiences are invaluable to learning science, and as emphasized in the post-secondary science education literature, this is arguably more pronounced in chemistry (Campbell et. al, 2020). Since chemistry units and their LOs are core to Manitoba's Grade 9 and Grade 10 science curricula and prioritized by teachers amongst the four clusters in each grade, the loss of laboratory and collaborative work in these units were of particular concern to teachers during the pandemic. For example, although teaching some of the scientific concepts found in the Grades 9 and 10 chemistry SLOs, such as the chemical composition of binary ionic compounds such as copper II sulfate and how to write its chemical formula are easily taught without practical work; teaching the physical and chemical properties of such compounds such as its blue colour, and how it behaves in a chemical reaction (MEY, 2003, pp. 2.20-2.23) are not—and require student investigation and experimentation while in collaboration with other students. Many examples of curricular direction for teachers to provide collaborative teamwork learning opportunities for their students, such as “Students work in pairs and practice writing chemical formulas for binary molecular compounds” (MEY, 2003, p. 2.12) are found throughout the Grades 9 and 10 documents, but remote teaching and physical distancing when in-class meant such routine

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

learning activities were unavailable. Additionally, Aguirre and Selampinar (2020) found that adaptations for the remote delivery of chemistry lessons during the pandemic failed to provide students with a full learning experience, and Tigaa and Sonawane (2020) found students required step-by-step directions and constant reminders to assimilate chemical concepts when learning remotely. The Grades 9 and 10 teachers faced similar issues when teaching chemistry remotely, and opportunities for students to experience authentic wait times to critically think about procedures, and what they are doing as they investigate and experiment for instance, were lost. Furthermore, as one teacher pointed out: “Many kids say, and I see this at the higher levels, they don't like labs because it makes them think, it kind of gets some out of their box and out of their comfort zone” (P9), they made it clear that some students are also aware of the tremendous value of laboratory work to reaching higher levels of thinking and learning. When students are challenged to think critically and ascend the levels of Bloom’s taxonomy to apply, analyze, evaluate and create scientific understandings through authentic laboratory work (McGuire & McGuire, 2018); and reach higher levels in the BSCS 7E learning model to explain, elaborate, evaluate and extend their scientific understandings, teachers and students alike recognize that scientific literacy is advanced. While accentuating the need for students to participate in authentic science in order to learn science, “Now that the pandemic is over, kids are tired of sitting down in their desk and *listening to people talk*. They had two years to do that and I think now it’s time to really explore what science is” (P4)—and to embrace the NOS and extend their thinking beyond remembering and understanding. While some teachers relayed their value for practical work to learn science through its frequent use in usual practice, other teachers focused on its value through reflection of its absence in their pandemic practice, sharing: “If there was one thing, if I could’ve gotten a bit more hands-on stuff in” (P8); and,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

I really don't feel like the pandemic was my normal teaching. So, to be honest, I think I've abandoned more of the practices. It's just not who I am as a teacher.

I'm somebody who likes to be hands-on. I'm somebody who likes to have things that the kids see on a regular basis (P2).

While exposing an important component of their identity as a science teacher, this teacher's explanation that teaching science with practical work is core to their science pedagogy is a view other teachers echoed, and I relate to. While these science teachers maintained an evolving, strategic lens throughout pandemic restrictions that limited the practical and collaborative student work they highly value to teach science; another teacher, guided by its profound loss to their teaching indicated, "For me, getting back to [hands-on teaching] has been super important. I have to admit I'm not missing COVID, and its practices" (P10). Despite the challenges throughout the pandemic period of science instruction however, one teacher affirmed, "*but we did it*" (P1). An important question overriding their enthusiasm however, and of significant relevance to this study and the advancement of student scientific literacy—is how effectively did they perceive they did it?

Theme Five: These teachers adjusted their instruction and assessment in response to limitations on practical and student cooperative work during the pandemic, providing students with various alternative learning activities while remaining significantly reliant on digital technologies.

As these Manitoba Grades 9 and 10 science teachers responded to restrictions and limitations to practical work during the COVID-19 pandemic, they resourcefully adjusted their instruction and assessment in various ways. The Grade 9 and Grade 10 Senior Years Science curriculum documents indicate: "Deciding which learning activities to use is an important part of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

a teacher's initial planning. Teachers need to make deliberate, informed decisions about the best tools to use for each learning task" (MET, 2000, p. 22; MEY, 2003, p. 39), but when the best learning tools and activities were unavailable during the pandemic, teachers sought the next-best alternatives. Despite some debate about whether teachers should develop novel pedagogical practices or build on existing best practices (Gillis & Krull, 2020), the consensus among teachers was that when practical work previously central to their teaching was unavailable during the pandemic they turned to all available supports. One teacher emphasized, "This was the right time, I guess, for this to happen because we've got a lot of tools at our disposal" (P5). The widespread availability of the Internet for teachers and students during this period of lockdowns and restrictions became the champion in science education, as teaching and learning became dependent on it, according to these teachers.

As these teachers sought to become proficient in digi-pedagogy and worked hard to craft new learning opportunities despite the lack of time to adapt, one pointed out: "We're in this weird environment... we can adapt. This is being thrown at us, and it's not great, and it's not fun, but we can teach some problem-solving skills" (P6). I admired their ambition and flexibility to capitalize on opportunity to continue to teach science without practical work, and in union with creative educators globally as they strived for quality teaching (Bhamani et al., 2020). With the race for new technology to provide and enhance remote learning opportunities at the forefront of education during the pandemic, Giordano and Christopher (2020) informed that educators across all disciplines and educational levels stepped in to offer innovative approaches. MacIntosh (2021) reported that some Winnipeg high school teachers organized conferences featuring international guests; that some schools had transformed facilities to develop online lessons; and that remote learning prompted teachers to test out a multitude of digital teaching tools—all

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

revealing the resourcefulness and responsiveness of local educators engaging in a new style of teaching and learning as MacIntosh stressed, “success hinges on attitude” (p. A9). But it was incredibly challenging, as one participant teacher explained:

If we needed large equipment, it just wasn't practical to move it, so some of the things I was able to come up with, like smaller experiments with smaller equipment...but even then, just trying to teach in the pandemic and coming up with different ways of doing that, was *quite a thing* (P3).

Putting alternative instruction into place when practical work was restricted, although necessary, was fraught with barriers: “The newness of trying to adapt to the pandemic... I didn't have a lot of activities that the students could do prepared beforehand, so I couldn't think of anything... it was hard” (P9). Without the extensive and accessible digital world at their disposal to seek instructional alternatives to practical work, attempts to teach the Grade 9 and Grade 10 science LOs would have been exceptionally problematic as one teacher acknowledged: “I didn't have a lot of things for them to really do at the Grade 9, Grade 10 level” (P11). Although these teachers have expertise in their curricula and in practical teaching approaches, one acknowledged, “We've got a lot of tools at our disposal. I just feel that I under-utilize them because of my lack of technology know-how” (P2). All of the teachers felt that a reasonable level of technological proficiency was critical to propping one's ability to successfully adapt science pedagogy to a remote platform—but while some brought technological knowledge and knack into the pandemic, others were less skilled in digi-pedagogy. Two teachers stated rather frankly, “I didn't do anything new” (P2) and “I'm just gonna say no” (P9), when asked if they had created or implemented alternative science learning activities to replace traditional ones. Another teacher,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

attempting to maintain some opportunity for hands-on practical work through remote instruction recounted:

In Grade 9 I found a little experiment they could do at home on the camera in front of me, just gathering some little things around the house to experiment with static electricity. That's something I've never done since, because that was much simpler and less structured than what I would do in the classroom (P5).

While teachers continued to teach science to their students from afar, with little time afforded for the development of alternative science lessons and coupled with the fact that many teachers “did not know how to do it” (Babinčáková & Bernard. 2020, p. 3296), some remote lessons crafted by teachers, including myself, were indeed simple. Moreover, despite teachers putting in their best efforts (Kim & Asbury, 2020), experiments done at home were not considered as enjoyable, nor effective skill-building substitutes compared with those done in school. As noted earlier, while online teaching is a virtual process (Meng et al., 2020), hands-on sensory input is important for developing scientific literacy (Cutri et al., 2019); and while “The world changed a lot during [2020-2022]... the principles of teaching and learning did not” (Borish et al, 2022, p. 18). With the scholarly view that alternative forms of education during the pandemic had variable efficacy (Reimers, 2022), interest in the alternative approaches implemented by Manitoba Grades 9 and 10 teachers and their perceived effectiveness to foster scientific literacy was elevated.

The demands on science teachers given the practical requirements for teaching this subject left them struggling to find effective alternatives to teach their curriculum. “It provided a lot more work for the teacher to find things to do, to be very creative, to make connections to the curriculum and find things that the kids *could do or watch*” (P7) explained one teacher—with the overall aim to keep teaching science to their students over any consideration of scientific literacy

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

development. When asked what alternative science learning activities they had implemented to replace traditional practical ones, one teacher explained, "There's a lot more video lessons, and a lot more video movies that they would be watching" (P6); while another accentuated:

They shifted from exploration and supervised investigation to videos of, *this is what we would have done*. This is what you *would have* participated in. But watch the video, you'll get the gist of it.... I don't think it can *ever replace* the doing of something to accentuate or reinforce the theoretical learning (P1).

While revealing a picture of the extreme pivot from experiential learning during the pandemic, this teacher also revealed the perspective that although video alternatives to replace practical learning allowed teachers to keep teaching, they served as compulsory substitutes versus effective replacements for experiential learning. Another teacher echoed this view:

Normally in Grade 9 science for example I would do a lab where they get to extract DNA from strawberries and see it macroscopically, and I've always had great reactions from kids... but what I would do during the pandemic is I would find a video of somebody else doing it, and there's not much value in that... not being able to touch and manipulate. The kids are losing a lot of value in that type of learning, and I had a very hard time trying to find anything that remotely compared. I found I was barely scratching the surface of what they should have been able to achieve if they were in class (P10).

While emphasizing the extreme loss of practical opportunities to touch and manipulate in lab work to learn DNA science, this teacher's perspective that comparable alternatives do not exist was a view shared by all participants. Scholars revealed concern for laboratory skills acquired through video demonstration versus practical learning, and who argued that video alternatives

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

fail to meet teacher benchmarks for inquiry and authenticity (Heng et al, 2022; Kelley, 2020), and these teachers' concerns were aligned. It was further noted that the loss of valuable student reactions that typically accompany authentic practical work in Grade 9 science such as the excitement students express when isolating and handling DNA, might substantiate the compromised development of scientific skills and attitudes. Another teacher emphasized, "It's also super important getting students to question what they're reading and what they're hearing, and getting them to *actually do science*, rather than sit down and listen to science from a teacher or a video" (P4). Videos cannot adequately replace laboratory learning and can lead to student misconceptions (Chen, 2022); and as previously noted, when students engage in hands-on manipulation, they have opportunity to learn the most from performing a procedure incorrectly—something unavailable in best-practice videos (Kaup et al., 2020). One teacher's comment offered an excellent overview of what videos cannot do: "Hands-on experimentation as well as group work, that social aspect of doing experiments together and helping each other out, figuring out what went wrong or what worked... *was lost*" (P5). When teaching high school science, I learned firsthand that learning opportunities stemming from student mistakes such as an imprecise measurement for example, or failure to control temperature during an experiment, are as invaluable as the mistakes made when first learning other practical skills such as how to ride a bike. "Science should be portrayed as intense human activity full of trial and error, that is influenced by cultural priorities and perspectives" (MET, 2000, p. 17; MEY, 2003, p. 26); and without authentic opportunities to make mistakes, students lose opportunity to develop critical thinking and problem-solving skills that are required in scientific practice. Robertson (2018) contends one's conscious recognition of their misunderstandings is an important element of metacognition, and as skill development accompanying student self-assessment is

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

metacognitively significant for experiential learners, students lose genuine opportunities to advance their scientific literacy when watching videos to learn science.

Providing learning opportunities conducive to developing scientific literacy without practical work was a profound challenge for teachers (Evans et al., 2020), and without effective alternatives one frustrated teacher admitted, "I would have to say that I don't know if I was doing a good sales job on how critical science is to us, when I was handcuffed" (P7). Loughran (2011) had emphasized that developing learning activities that work to bring content to life on a daily basis acknowledges the real demands of teaching on a daily basis, but doing so amid pandemic restrictions through alternative methods was exceptionally challenging for teachers (Pregowska et al., 2021). Yet, Chan et al. (2020) believed science teachers had to shed their fears of trying and practicing new and different pedagogies while teaching remotely, in their attempts to develop student-centered pedagogical toolkits with some form of practical work. As Grades 9 and 10 science teachers sought new tools to adjust their daily instruction and assessment, they had little choice but to reach beyond video instruction and become creatively resourceful; but as teachers continued their attempts to replicate the experience of practical exposures without proper training, it became clear that some were not successful. Although some Grades 9 and 10 teachers described turning to their colleagues for support, "Without resources and supports in place" one admitted, "it was absolutely like the blind leading the blind" (P2).

These teachers seemed to learn quickly that "the pervasiveness of technology into daily life not only reinforces the importance of scientific literacy" (MET, 2000, p. 1.2), but an exploration of technological tools to support pandemic pedagogy was required. Some teachers united in their schools and science departments to create alternative learning materials, and students benefitted as teachers became increasingly competent with online platforms and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

interactive science websites, simulations and games while adjusting practical learning activities.

Most of the teachers emphasized an increased reliance on digital technologies to teach science during the pandemic, while a few highlighted specific online resources: “ExploreLearning, that’s an awesome website” (P5); “The use of Edpuzzle was a huge tool that I used during all of Covid” (P3);

I used a lot of Edpuzzle and ExploreLearning. ExploreLearning is expensive but they have um, incredible gizmos as they call them, which are like apps, and they come with fully detailed student worksheets... It’s *so* good. I loved those, and I continue to use those, and we, have as a department, continued to advocate for paying for this resource, because not only is it great for students, but it supports staff because it gives full answer keys and all sorts of other resources with it... for having hands-on in science become digital, this was *by far* the best resource, and they cover like everything (P1).

Opportunities to enhance science education emerging alongside remote teaching were strongly tied to the advancement of digital technologies and telecommunication networks like 5G (Ting et al., 2020), which supported new learning platforms (Sayer & Braun, 2020). Yet, although interactive scientific demonstrations and experiments might help mitigate the barriers to rich remote learning experiences (Babinčáková & Bernard, 2020), scholars such as Waight and Neumann (2020) recognize that substantial increases in computing power along with digital technologies, simulations and modeling tools cannot alone help students become scientifically literate unless they are incorporated into meaningful curriculum. Moreover, they can only ‘take life’ through a teacher, whose “knowledge is the biggest factor in the implementation of the curriculum” (Dube, 2020, p. 151). As such, Grade 10 teachers mentioned another website that

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

helped bring life to their curriculum: “I used some stuff off the PhET website”; and “I would say during the pandemic some of the PhET labs worked pretty well, like the simulations... kids really seem to like those”, and I concur. Some of the PhET simulations are excellent, such as the MovingMan for instance which allows students to manipulate a digital character at different speeds and in different directions with accompanying graphical data. This simulation firmly props learning for three SLOs in the Grade 10 In Motion unit: “Analyze the relationship among displacement, time, and velocity for an object in uniform motion”; “Collect displacement data to calculate and graph velocity versus time for an object that is accelerating at a constant rate”; and “Analyze the relationships among velocity, time, and acceleration for an object that is accelerating at a constant rate” (MEY, 2003, pp. 3.2-3.7). While my colleagues and I found value in the use of this PhET simulation prior to the pandemic, I had routinely observed my Grade 10 students struggling to assimilate these relationships without my in-person clarification and direction when they were using the website. During the pandemic, when I was unable to offer guidance to my students while using the MovingMan remotely, although it was difficult to properly assess their learning it was clear that many did engage and enjoy learning with this interactive simulation—giggling in a Microsoft Teams meeting while launching the man in a tuxedo into a brick wall at high speed. As Worrall et al. (2020) had suggested that carefully designed simulations could help to keep post-secondary chemistry students engaged in some practical work in a remote environment; and Torres-Freyermuth et al. (2022) indicated other post-secondary studies in physics revealed the value of playfulness achieved in virtual laboratories helped to engage students in the learning process, some students likely benefitted from the novel virtual tools science teachers incorporated into their remote science lessons. Yet,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

with an awareness of the limitations of online simulations to replace practical learning and the cognitive abilities of their Grade 10 students, another teacher proposed:

I would say that the PhET simulations have been good, although they are nice to complement hands-on. I don't think that they can...or replace the doing, but showing before and after labs. I don't think it furthers scientific investigation, unless you have kids who are able to critically think and analyze, but some kids aren't there yet. Some kids are able to identify, list and organize, but aren't necessarily able to do that critical thinking piece, so you could have an activity I think, that could advance scientific literacy for kids who are at the upper end, but it can't be an activity that I would assume or could hope that would advance scientific literacy for all of the students (P4).

This teacher's view of the range of student abilities in Grades 9 and 10 general science courses is an important one, and one that I relate to from my science teaching experience. With an understanding of our students' abilities, in order to ensure that all students benefitted from the practical learning activities we implemented my colleagues and I routinely organized our students into lab groups with assigned roles and responsibilities. But the online instructional environment meant students were on their own to learn whatever they could while using interactive websites like PhET. One Grade 9 teacher provided a different perspective, explaining another online simulation used to support conceptual understanding of electrical circuits and associated mathematical relationships taught in the Grade 9 Electricity unit:

There is an online circuit building platform where we're not limited to our number of wires and clips so we can have technology representing what we're

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

trying to do.... It's cool and I would say it was sufficient. It actually might have helped a little bit more with the mathematical concepts of current (P7).

While acknowledging value in learning these concepts experientially via hands-on work, this teacher's view that a digital alternative might be sufficient was notable, and of potential importance to perceived student scientific literacy development during the pandemic. It was further noted, that as equipment limitations hindered this teacher's ability to teach these important LOs through practical work prior to the pandemic, this online circuit building platform might be of ongoing value to their teaching, and school's Grade 9 science program.

The participating teachers described incorporating a variety of other digital technologies into their alternative instruction and assessment while traditional teaching was suspended during the pandemic: "One thing I did do a few times and still do, was almost like a scavenger hunt, but online... leading students to different websites, different articles and different videos, just accessing different media sources" (P3); "A lot of the projects I had from my clusters were easily adapted to a digital form... they could do a digital brochure" (P8); "Doing a lot of social media type stuff, like taking pictures and showing examples of their knowledge that way" (P6). As digitally mediated remote learning promotes student autonomy and allows learning to become personalized, self-paced and self-evaluated (Taguchi, 2020), and Grade 9 and 10 students are among the digitally literate and highly connected generation of learners ready to invest in technology (Byrnes et al., 2020), Manitoba students were poised for potential success in remote learning. Although teachers had relied on various online alternatives during the pandemic mainly to replace restricted practical work, some described expanding their teaching toolbox into the digital world following their pandemic experience:

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

I now have all my lessons for the most part digital... So, if a kid is gone, I can send them my lesson, and can now see if they actually watched it. So yeah, totally have tons of better tricks and things I can pull from... I've taught Grades 9 and 10 science at least 30 times each, so I have a really good understanding of the curriculum and materials, and can, on the fly, pull something very easily now (P1).

It was noted from this teacher's account that extensive science teaching experience may have eased the strain of adjusting instruction, as teachers typically develop and amass a cache of resources throughout their careers—of potential value for crafting alternative learning activities and helping to prop student learning in science. Several teachers described other digital pandemic practices of enduring value: “I added little things like ‘watch this video now’ during COVID, and I've left all that kind of stuff there” (P9); “I've made some changes due to the pandemic... put notes up so that kids can access from home. And just making things more digitally available to kids now than they were before. It benefits kids who are away” (P3); and,

I think some of the technology stuff has been probably one of the biggest takeaways. The kids access Teams on a daily basis now, everything is posted there, and certainly have more access to what they've missed than they ever did before. They're still going to miss the, the hands-on side of it, but at least they can still have the content base that goes with it. So that part has been good (P5).

As these teachers described significant merit in the ongoing digital access of course materials, missing the “hands-on side of it” in science as previously discussed meant students might not advance their functional scientific literacy—but the teachers considered the variety of digital technologies as the best alternative tools to replace practical work during the pandemic. I noted

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

however that the interview discourse regarding these alternatives centered on teaching science content, with little or no discussion of opportunities lost for procedural skill development or practicing positive laboratory attitudes.

Although the Grades 9 and 10 teachers largely focused on digital adjustments as they responded to restricted laboratory or hands-on learning activities, they also described explicit details of other instructional approaches queried: demonstrations, class discussions, oral presentations, student project work, written assignments and research.

The teachers were clear: “No demonstrations during the pandemic” (P9); “Demonstrations definitely decreased in frequency” (P8). Some teachers struggled when stripped of these usual instructional tools:

I like to be creative and off the cuff at times when I’m teaching, and I didn’t have the opportunity to really do that when we were doing the remote, or that synchronous part. You had some students in your room, plus some students online at times. You can’t multitask or do a demo, or you’d miss when somebody is trying to ask a question from home, and don’t have the camera on you when you’re answering a question in class, so four kids at home miss your visual demonstration...it limited my teaching (P1).

Instructional methods including demonstrations tactically woven into the daily instruction of some science teachers like this one disappeared along with practical work during the pandemic, and another teacher suggested the extreme impact of this loss:

The little short snap or two-minute demos you model for them, here’s acid, here’s base, be careful, try it...just went away. And if you don’t build that

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

curiosity at the beginning of class, that little shock and awe, yeah, different outcome for sure (P7).

With limited time and laboratory opportunity afforded to teach some SLOs such as “Experiment to classify acids and bases using their characteristic properties, including indicators, pH, and reactivity with metals” (MEY, 2003, p. 2.24), teachers might adapt with quick and effective demonstrations as this teacher described or by adding a highly reactive metal to an acidic solution for example, as “Experiences of intense involvement are optimal opportunities for teaching engagement in learning” (MET, 2000, p. 21). Moreover, this teacher’s reference to building “shock and awe” to engage and inspire students aligns with the view that “discrepant events can be a powerful tool” accompanying demonstrations (MET, 2000, p. 22; MEY, 2003, p. 39). For example, the attraction of a neutral object is a discrepant event that challenges students to refine their understanding of the particle model of electricity (MET, 2000, p. A62). Teachers might teach the Grade 9 Electricity unit SLO “Explain how a discrepant event can be used to evaluate the particle model of electricity” (MET, 2000, p. 3.6) by demonstrating that either positively or negatively charged objects can attract neutral ones, and in doing so, create cognitive dissonance for students. For example, when rubbing silk on a balloon, the silk acquires a positive charge; but when rubbing silk on glass, the silk acquires a negative charge—yet both attract small bits of paper. After learning about subatomic structure, where negatively charged electrons are attracted to positively (oppositely) charged protons; and that like charges repel each other and unlike charges attract, students often conclude, incorrectly, why the paper bits behave as they do (p. 3.6)—and must refine their understanding of the particle model. In my experience, Grades 9 and 10 science teachers including myself commonly use demonstrations to introduce discrepant events, which take little time but offer valuable moments for students to learn scientific concepts.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

While cognitive strategies associated with practical work in science education include discrepant events (Agarkar, 2019); notable qualities of the nine styles of learning described by Petersen and Kolb (2018) of importance to developing scientific literacy include meaning created through observation and reflection, and disciplined involvement in abstract reasoning and logic—both may be enhanced when teachers incorporate discrepant events as a cognitive strategy. For example, asking Grade 10 students their thoughts about when a textbook and a pencil will touch the ground when dropped from the same height at the same time, is a powerful demonstration likely to stir some cognitive dissonance and helpful to teaching the In Motion SLO “to outline the historical development of the concepts of force and “natural” motion” (MEY, 2003, p. 3.8).

The curriculum standards state, “demonstrations can arouse student interest and allow for visualization of phenomena”, and are a valued instructional tool in the Grades 9 and 10 curricula (MET, 2000, p. 22; MEY, 2003, p. 39). Further, in my opinion, demonstrations can extend the array of practical experiences that science teachers routinely provide to students beyond structured lab work, and can allow students regular opportunity to learn science, experientially. For instance, when teaching Grades 9 and 10 science, my colleagues and I would routinely invite students to participate in the demonstrations we conducted, such as doing a flame test to hear the “pop” of hydrogen gas for students to learn about chemical properties and reactions; or throwing a raw egg at a cloth wall and a brick one to compare the forces on the egg while learning about the concepts of momentum and impulse—each fostering much excitement and engagement of all students. Teachers could not do demonstrations like these when teaching remotely from their homes, and although some may have done simple demonstrations in front of a camera while teaching remotely from their schools, they lacked any opportunity for in-person visual and interactive learning which usually accompanies this approach. As expressed by some of the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

teachers, the loss of demonstrations to regularly engage students may have impacted students' ability to learn science and failing to pique the wide-eyed interest of Grades 9 and 10 students may have resulted in additional impacts to their class participation.

While teaching remotely, my experience paralleled all of the participant teachers, as some shared: "Class discussions, gone. You try to, you couldn't get anybody to speak up" (P9); "You can only have one kid talking online... so I certainly found it leaned heavily on me... as opposed to group discussions happening" (P1); and,

Class discussions when the students were at home were limited... you'd have some student interaction through their microphones, but it wasn't the same as in class where students can easily blurt out anything or raise their hand or answer questions on the spot. They'd have to unmute, and who knows if they're just lying in their bed, so there wasn't as much interaction or class discussion. It was more so me talking the whole time, or most of the time anyways (P5).

While aptly capturing the authenticity of typically curious and enthusiastic Grade 9 and Grade 10 science students and reiterating the shift to teacher-directed instruction, these teachers' comments generally summarized the struggle to foster effective class discussions. Aside from a few outgoing or motivated students initiating or contributing to online discussions that I led in the 2020 spring semester, most did not participate; and while unable to observe them I also wondered if they were watching, listening, or thinking about the topic of discussion. Although scholars emphasize that online collaborative opportunities were not as effective as those afforded in-class (Garcia-Vedrenne et al., 2020), during the pandemic these teachers were largely unable to facilitate effective online interactive discussions between their students—which Croce and Firestone (2020) posit are necessary for students to deliberate questions for further analysis and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

investigation. During pandemic periods of in-person instruction, one teacher indicated “We couldn’t let the kids work in pairs, or groups or anything like that and that was pretty unfortunate, they enjoy it and can get a little discussion going on between themselves and that is helpful” (P6). Group and class discussions are useful to spark interest in a topic or LO, to activate prior knowledge, or to generate ideas for solutions to problems for instance (MET, 2000). When teaching science in-class prior to the pandemic, my colleagues and I would frequently instruct our students to “listen-think-pair-share” (MET, 2000, p. 22; MEY, 2003, p. 39), and many Grade 9 and 10 students would eagerly take part in this activity. Overall, as teachers attempted to teach LOs requiring student interaction during the pandemic, the implications of limited opportunity for students to participate in co-operative discussion, planning, lab work, analysis and explanation of results to build critical scientific literacy skills and attitudes (MET, 2000, pp. 0.3-0.7; MEY, 2003, pp. 0.3-0.7), were likely quite extensive.

Along with the collapse of demonstrations and meaningful classroom discussions, all teachers reported a similar result for student presentations. Examples of teacher statements include: “My oral presentations stopped” (P10); “Oral presentations, virtually, yeah nonexistent because we had time limitations” (P3); “Presentations... we didn’t have a ton of those, it was tough because they had to mask and it was really difficult to hear kids” (P2). To learn many SLOs, GLOs and Cluster 0 SLOs in the Grades 9 and 10 science curricula, students must collaborate with classmates, and the curriculum documents direct that students should present their interpretations and explanations through individual or group presentations (MET, 2000; MEY, 2003). One Grade 10 teacher explained, “I always had them do the extreme weather event project as group research and presentation, but during the pandemic just had them submit their [individual] PowerPoint to me” (P9). The opportunity to learn the Weather unit SLO: “Explain

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the formation and dynamics of selected severe weather phenomena" (MEY, 2003, p. 4.25) which normally allowed this teacher's students to learn through group collaboration to promote skills and confidence in leading discussions, explaining, and presenting, was replaced with an individual online report that left students short of an opportunity to develop cooperative competencies. Furthermore, instructional strategies involving collaborative teamwork "encourage students to learn from one another and develop teamwork skills... and can lead to increased understanding of content and improved thinking skills" (MET, 2000, p. 23; MEY, 2003, p. 39). Therefore, teachers can teach beyond the cluster SLOs to include GLOs and Cluster 0 SLOs that require student interaction to achieve. Overall, these teachers' comments suggest that their efforts to promote the development of scientific literacy were hindered by the loss of student-led presentations given the immense benefit of these presentations in facilitating student understanding of scientific concepts; fostering collaborative learning skills; and helping students develop positive scientific attitudes.

The interview participants shared that student project work faced a similar sharp decline during the pandemic. For example, one stated "No projects, because you couldn't. You could be sure that they wouldn't do anything outside of whatever you had them do in class" (P1), while another teacher added: "Project work became less frequent because of limited number of days... one per unit and individual [done alone]... hands-on practical work was less emphasized, so projects were ultimately less emphasized" (P8). Highly valued PBL offers enormous potential to enhance functional scientific literacy as students investigate, collaborate and deliberate relevant questions that connect core curricular knowledge with procedural knowledge and skills (Croce & Firestone, 2020; Juuti et al., 2021), but even simple projects weren't possible during the pandemic, according to these teachers. While explaining that project work was impossible or at

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

least limited during the pandemic, in part because science projects often require practical groupwork; another teacher expressed a contrary view: "Project work, because they had so much more time, some was very well done... but by keen students that probably would have been doing that anyway, they had more time and the ability to focus" (P5). The general message from teachers, was that academically motivated students pursued independent learning through the coursework assigned; while other students struggled to engage in remote learning because the practical component was excluded.

The pandemic offered opportunity for classroom innovation, and teachers worldwide reported numerous positive outcomes from creative pedagogy, but these were unfortunately, limiting (Giordano & Christopher, 2020). Teachers were disadvantaged with the loss of a repertoire of instructional approaches during the pandemic: practical work, demonstrations, oral presentations and project work and were left with perceived inadequate alternatives. The loss of valuable experiential learning opportunities through real-world, place-based, co-operative learning was markedly emphasized by one teacher: "We weren't allowed to do field trips... so the pandemic took all of that out of the equation. *Big change!*" (P2). As this teacher indicated, and in my experience as a Grade 9 and 10 science teacher, field trips are an integral element of science programs in many schools; and field work is supported in the Manitoba science curricula instructional philosophy (MEY, 2003). Providing students with authentic opportunities to observe, interpret and experience local scientific practices within the context of PBE, PBL or SSI; and to learn about, make informed decisions, or take action on meaningful local issues such as planting milkweed plants to support monarch butterfly populations can help them to develop functional scientific literacy (Anderson et al, 2020; Calabrese Barton & Tan, 2014). While Tal (2013) suggests functional scientific literacy is advanced through such meaningful contexts that

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

allow students to engage in their learning through cognitive, affective and social aspects; PBE scholars propose that scientific literacy is enhanced when students address authentic questions in local “places” or home communities (Kim et al., 2019), which field trips provide. Furthermore, while grounded in experiential and active learning theories, Anderson et al. (2020) maintain that opportunities for PBE promote the development of scientific literacy as students can make authentic and personal connections—and for Grades 9 and 10 learners who enjoy being physically active, perhaps to a greater degree.

As these teachers adjusted their science instruction in response to restrictions on practical and collaborative work that eliminated many of their trusted approaches, most of them stressed: “There were more written assignments” (P4); “There was a lot more paperwork... a *lot* more... paper pencil, a lot of, on their own, you know, instead of working with a group” (P1)—revealing their overall recognition of the enormous impact the pandemic had on their usual teaching. One teacher reflected: “The pandemic taught me just how important all the hands-on stuff is, and how we lost that. If you're teaching science with worksheets, then *you're doing it wrong*” (P9). When science teachers taught science and students tried to learn it by doing paperwork during the pandemic, versus the concrete experiences that are required to create meaning through observation, reflection and practice (Petersen & Kolb, 2018) they cannot achieve higher learning described in the BSCS 5E or 7E learning cycle. As previously noted, science education scholars are in agreement with this perspective (e.g., Kelley, 2020; Layton, 1991), arguing that students require practical action and authentic experiences to build conceptual and practical scientific knowledge, critical thinking, and observational skills to develop functional scientific literacy—which cannot be taught through worksheets.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

With limitations to learning modes and styles conducive to learning science during the pandemic—particularly experience and action, an elevated importance of other aspects of learning such as analyzing, thinking and imagining (Petersen & Kolb, 2018) became more suitable and teachers assigned more written work and research to teach scientific concepts. Although procedural skills and accompanying scientific attitudes best learned through practical work are largely excluded through this approach, one teacher relayed an important perspective: “During the pandemic, there was more research... something students could take home with them” (P11), illuminating the point that some learning was done in students’ homes where students may have engaged in some form of cooperative learning with family members, or through digital communication with their classmates. Furthermore, as learning activities “that involve student research are one of the most effective ways to individualize instruction” (MET, 2000, p. 22; MEY, 2003, p. 39), as teachers adjusted instruction to include more research, some students may have benefitted. These teachers reported: “We had to change a lot of the activities that we did to be more individualistic” (P5); “It did give me a bit more time to focus on some activities that I could do, that were more individual based” (P2); and “I created some individual projects, that I can still use now” (P9). Although fully aware that the scientific competencies prescribed in the Grades 9 and 10 LOs are necessary for student development of scientific literacy, when physical distancing prevented collaborative work between students, some teachers found value in teaching different skills to their students. Bhamani et al. (2020) reported national findings from a study conducted in India, revealing student self-exploration and independent active work as useful learning strategies during the pandemic, as students accepted responsibility for their own progress. This study shows that at least some Manitoba teachers also continued to teach their students using independent instructional approaches, even though some science LOs

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

were impossible to teach. Tienken (2020) had made the compelling point that remote learning is so highly dependent on factors outside of school control, 'independent learning' could be considered a more suitable term for science education during the pandemic, and some Manitoba teachers may have agreed. The perceived benefits accompanying individual work in Grades 9 and 10 science however, meant that student opportunities to develop some scientific literacy concepts, skills and attitudes were often set aside. One resourceful teacher however, enjoyed creative success in adapting a practical inquiry-style learning activity for individual students during the pandemic:

It opened up other ways to do hands-on learning, such as à la carte labs—individualized small-scale discovery-based labs where students are provided their own equipment at their desks and prompted to complete a discovery-based laboratory procedure (P11).

With consideration to equipment limitations other teachers had described, alternative activities like this one might depend upon physical space and school resources.

Other teachers provided another perspective, that "The pandemic forced more independent learning, and put the responsibility on some learners that typically, you know, tagged along and benefited from the leaders in their group who learned the skills and concepts" (P4). This view might bear relevance to students' overall learning in science, since many extracurricular activities and student jobs outside of school were on hold during the pandemic and most students had a significant amount of independent time to invest in their learning—if motivated to do so. Reimers and Schleicher (2020) assert that expanding learning through online technologies beyond school walls, supports student development of 21st century competencies such as independent research and higher order cognitive skills. As the implications of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

pedagogical shifts vary with individual student characteristics, independent learning opportunities might have afforded some students with very valuable learning experiences. Yet, the participant teachers encountered diverse barriers while adjusting their pedagogy, and at least one teacher struggled to provide suitable independent learning opportunities for their students:

It was *very, very hard* to coordinate some kind of self-directed learning activity.

And admittedly I wasn't prepared with any of these beforehand, or didn't have time to do it during the pandemic. So, kudos to some teachers who are excellent at that, and were able to coordinate something where students could do those self-directed activities on their days at home, but yeah for me, I wasn't able to do that (P2).

Although some teachers were unable to develop alternative self-directed learning activities, each teacher found ways to adjust their instruction in Grades 9 and 10 science and some reflected positively. One teacher shared "I find that in a way it's improved my teaching and kind of broadened my horizons" (P10), suggesting their professional growth during the pandemic had expanded into new instructional territory. Another teacher expressed a similar view, "[I am] more aware of the types of learners I have and how I can inspire my students" (P5). These teachers echoed others who described an overall increased awareness of individual student needs through the pandemic as beneficial to their future practice; and joined teachers worldwide who reported creatively improving their teaching during the pandemic, to meet a greater breadth of student needs (ICET, 2020). As such, these Manitoba science teachers planned instruction during the pandemic based on perceived student needs with curricular backing to do so (MET, 2000); even though more fulsome scientific literacy may not have been addressed.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

To summarize, the Grades 9 and 10 science teachers adjusted their instruction when restrictions to practical learning were mandated during the pandemic, and while teachers perceived these alternatives were adequate to keep teaching science, they felt that their students were disadvantaged without hands-on learning. As discussed, the science education literature is clear that regular authentic practical experiences are necessary for students to acquire functional scientific literacy but teachers were unable to provide these for their students with pandemic restrictions in place—and demonstrations, oral presentations, project and collaborative work were similarly restricted. In their place, the teachers described greater reliance on digital technologies, videos, written assignments and research, as they adjusted their instruction. However, these alternative instructional approaches did not allow teachers opportunity to promote the full range of scientific skills necessary for student scientific literacy (MET, 2000), or to provide authentic opportunity for students to practice cognitive and metacognitive processes that are also required for its development (Natale et al., 2021). Consequently, these science teachers were hindered in their ability to advance functional scientific literacy during the pandemic with the alternative activities that replaced practical work.

The complexity of teacher understanding and practice of alternative methods compared with in-person practical work resulted in wide-ranging pedagogical implications.

As teachers made adjustments in their instructional approaches, most found it difficult to assess whether or not students were learning the scientific concepts, skills or attitudes they attempted to teach. This was evident in the teachers' comments: "I really couldn't entirely assess what they got out of it, because I couldn't see what everyone was doing" (P7); and

The whole teaching, shifted onto me, and I don't know whether it was effective.

It was hard to determine because we didn't have the proper assessments, we

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

didn't have any exams, and the tests were adjusted for the days that the students were there and not there (P1).

Without the ability to more fully assess learning, teachers were lacking important information to support their students day-to-day, to effectively plan their lessons, to assign meaningful grades, or to effectively report student progress to parents. The pandemic brought an urgency for teachers to re-structure their assessment practices, along with their instructional practices. Robertson (2018) contends that effective teaching requires teachers to monitor student understanding while engaging students to think deeply about the topic of study. However, the Grades 9 and 10 teachers were in general agreement that assessments conducted during the remote periods of learning were particularly fraught with difficulties to accurately gauge student learning.

When asked if they made changes to their assessment practices in Grade 9 and/or Grade 10 science throughout the pandemic, the teachers described adjusting student assessment in one of several ways: freezing grades in March 2020; exploring new approaches and outcome-based assessment; using digital tools and apps; reducing emphasis on testing and exams; and increasing formative assessment, and assessment as learning in their practice. One teacher's response stood out:

In [spring] 2020... *Yeah*, we changed some assessment practices, and then the next year the kids were so used to not having to do anything and just pass. It was quite a difficult task to get a number of them to work, even if they were away from school because they were sick, or for whatever reasons, or you had to shut down a couple of times and go completely remote again (P6).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

As discussed earlier, participants indicated that the government's decision to freeze grades in 2020 created ongoing difficulties for instructing and assessing students based on standards and rubrics they had previously established. Participating teachers adjusted their assessment practices in tandem with adjustments in instruction, but assessment options were also limited during remote teaching as teachers were not with their students, to assess them. Furthermore, processes became nearly impossible to assess, as only the products were available and these were of questionable reliability to gauge student learning. Teachers described an evolution of their assessment practices to coincide with altered learning expectations throughout the pandemic, with a general shift in assessment summarized by one: "I don't think we assessed as frequently at all as we had a reduced number of days" (P7). With greatly reduced student contact time throughout the pandemic, other teachers described paring down their assessment in conjunction with instruction yet were able to gather some evidence of student learning: "I didn't assess as much. I would still issue a common test though" (P3); "Well, there's no final exam, and there were no tests" (P9); and "I have simplified my assessments a lot... Tests are all very short and happen more frequently, and I like that a lot, *a lot*" (P1). Although evidence of student learning is ideally gathered through multiple sources that include observations of students and conversations with them (Davies, 2020), during the pandemic while teachers struggled to assess their students in a meaningful and timely way (Audrain et. al., 2021), some of these teachers found value in assessing fewer products. It was further noted that concerns about assessment validity may have accompanied the reduction in summative assessments of each science cluster or topic within a course. The teachers pointed out: "For any assessment, it was very difficult to have a true representation of what each individual kid knew" (P4); and,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

If I was testing online, you had to take into consideration, like what's the purpose of this assessment?... If they're doing these assessments at home, what are you really getting? Are you getting what they know, or are you getting what's in their book? Or are you getting what their friend is sending them? (P9).

Another emphasized:

It depended greatly on if they were doing the work at home, or if they weren't doing the work at home. And if the assessments were all being done at home. I don't think we were getting an authentic record of what they really knew and what they really didn't know. *Cheating was rampant* (P2).

While teaching Grades 9 and 10 students in 2020, my colleagues and I shared similar concerns when some teachers became aware that students submitted work that their friends, and in one case, their parent had completed. One participant teacher offered the perspective that "I guess, in some ways, the parents learned some science during the pandemic and may have been more able to support their kids" (P6).

As teachers adjusted to new forms of assessment, akin to instructional changes, others described value in trying new approaches. Some teachers turned to digital assessment tools, stating: "I think the biggest change I've seen is the use of different apps and how we can benefit from them. "We moved more to some digital formats, like Microsoft Forms for quizzes for example" (P2), and "I've learnt a lot about Quizlet and know students are using that a lot" (P3). One experienced science teacher said they "changed everything to be outcome-based assessment, as opposed to tests and quizzes and assignments" (P5). While expressing their understanding that school assessment practices were taking this direction in their school and in others, this teacher also explained that "this adjustment was very time consuming" (P5). Another teacher stressed the

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

need to look for “other ways to assess, including conversations of learning and artifacts of learning” (P5). While experiencing similar concerns when teaching remotely in 2020, some of my colleagues and I also decided that conversations with students by telephone might be the best way to assess general conceptual understandings of LOs taught; but as many skills and attitudes were not taught, they were not assessed. Although performance criteria are usually established between teachers and students during instructional design in alignment with provincial learning outcomes (MET, 2000), since many skills and attitudes LO were not taught, conversations about their acquisition would have been inappropriate. Another teacher added “It [assessment] changed a lot. It was the big takeaways, trying to get to those key essential outcomes, as to what do they really need for moving on” (P4). As “effective assessment is an integral part of learning” (MET, 2000, p. 23), and “assessment methods must be valid, reliable, and fair to students” (p. 4); most of the teachers sought to assess what they envisioned as essential, big idea priorities, as fair methods during the pandemic.

As the teachers interviewed described an overall shift to formative assessment, or assessment *for* learning; from summative assessment practices, or assessment *of* learning during the pandemic; some described an increase in assessment *as* learning (Davies, 2020). One teacher stated:

Now there's a lot more formative assessment and I reassess and reassess, and I'm trying to focus more on content mastery.... I found when giving kids an option of doing corrections, kids take the opportunity to do that, and that's been helpful for their content mastery.... I've also simplified my assessments a lot and don't even have tests. I've given kids more opportunities to assess their own

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

work, which has been helpful for them, especially those who take it seriously (P1).

This teacher's intentional adjustment to provide student self-assessments during the pandemic offered occasions for invaluable metacognition, a dynamic learning process integral to all five foundations in the senior science curricula (MET, 2000; MEY, 2003), and served an important goal: "To achieve the vision of scientific literacy, students must become increasingly engaged... in the evaluation of their own learning experiences" (MET, 2000, p. 4). Two other teachers described a similar adjustment, "Although the option of synchronous learning is not desirable, there are some lessons that were learned. For example, providing more diverse ways for online instruction, such as self-grading online assessments" (P11); and "Instead of assigning assignments for marks, I would just give them a completion mark and a key so they could self-evaluate... that's something I've certainly been using a lot more often" (P10). According to Davies (2020), when students are involved in their own assessment, mistakes become feedback they can use to adjust what they are doing and learn what to do differently next time. Allowing students opportunity to self-monitor, self-assess and self-regulate are important metacognitive skills that help students to actively engage in the learning process (Robertson, 2018), and gauge their learning progress (Withers & Schinske, 2016). As students set informed, appropriate learning goals, Davies (2020) contends motivation and achievement are also increased. Recent findings in science education showed that students acquired increased self-efficacy, motivation, persistence and retention when engaged in such metacognitive activities (Mutambuki et al., 2020). Although the shift in practice to promote self-assessment during the pandemic was spurred by concerns with unreliable information about student learning from traditional forms of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

assessment, unexpected learning benefits were the result, which may have propped student achievement of scientific literacy.

Another teacher added to the assessment discourse:

I think it [future practice] *should* change a lot. Really for me, the biggest difference has been the assessment piece. How am I assessing student learning? Science isn't about taking a test. I'm pretty sure there are no actual scientists out there who take tests all the time, I'm pretty sure they just ask questions and experiment and investigate. We did things a certain way pre-pandemic.... It's right to question what we did, and what we really actually need to do (P5).

This reflective and transformative perspective on assessment emerging from the pandemic teaching experience drew upon the true nature of science itself and suggests a review of best assessment practices to gauge student learning in Grades 9 and 10 science is required. The Grade 9 and 10 Manitoba Science curriculum documents provide “Suggestions for Assessment” that accompany each cluster SLO, which include tests, quizzes, laboratory reports, research reports, oral presentations, posters, pamphlets, and information technology presentations (MET, 2000, p. 1.9). While these suggestions are not meant to be limiting (MET, 2000) they may in part be limiting by providing few suggestions for student self-assessment. Yet, as “teachers are strongly suggested to develop their own assessment for Senior Years science based on their students’ learning requirements and the prescribed student learning outcomes” (p. 26), Manitoba teachers developed a variety of assessment strategies deemed appropriate during the pandemic. Yet, while reflecting on their assessment practices during the pandemic, two teachers provided a perspective shared by several others: “I probably would have [if able to go back] done more formative assessments, more frequently to check in with kids, and use that opportunity to check

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in with *how they really were doing*" (P1); and "I would have gathered more student input into how my approach to teaching the remote course could best serve my students' needs, during a scary time in the world" (P2). While poignantly ruminating their pandemic pedagogy and revealing interest in self-assessment, these two science teachers seized the essence of the COVID-19 teaching experience—while teaching science was their job, it was evident from their interview comments that student well-being was their leading priority.

While the creative efforts of Manitoba teachers, in harmony with other educators globally striving for quality teaching (Bhamani et al., 2020) pushed them to explore a variety of alternative and atypical instructional and assessment methods in science, these teachers expressed their diverse efforts to continue to teach science to their students, and to assess them during the pandemic. When asked about the effectiveness of alternative learning activities however, one teacher's response, "It always seemed to just end up, watch this video and do this worksheet, which is not, in my view, good pedagogy" (P7) echoed the collective voice of most others—that alternatives to practical work did not allow them to effectively advance student scientific literacy as they were able to prior to the pandemic, but were all they could provide.

Theme Six: These teachers reported students were less engaged in their learning when alternative approaches to practical learning were utilized.

The Manitoba government's announcement in March 2020 that "No student will be held back due to the COVID-19 pandemic, but students must actively engage in learning" (Manitoba News Release, March 31, 2020) resulted in a significantly contrary effect. The science teachers reported: "That simple government action allowed so many students to check out for the rest of the school year" (P1), and "A lot of students were disengaged from the entire learning process" (P11). In June 2020, approximately half of Manitoba students responding to a government

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

survey, indicated that although they were comfortable with remote learning, they did not like the experience (Manitoba News Releases, 2020). While most Grade 9 and 10 students enjoy learning science in-person according to the participant teachers, all of the teachers noted reduced student engagement when practical work was restricted. Examples of statements that were made are: “The engagement factor went way down, because the hands-on type stuff, that’s what gets the kids invested” (P9); “Hands-on is so important to keep them engaged and interested in science” (P4); and

The buy in was not there. Reading a bunch of stuff is not the same as being able to experience it, and try it in a hands-on practical type way. And so, everything I do, I try to do with purpose of engagement and try to build in as much of that hands-on as possible, and it just wasn’t, it just wasn’t there (P2).

The science education scholarship reports engagement as the first critical stage to learning science, as categorized in the 5E and 7E learning cycles (Suardana et al., 2018; Withers & Schinske, 2016). Furthermore, Petersen and Kolb (2018) highlight “experiencing” as the first of four modes in their experiential learning cycle, and first of nine learning styles—the intersection of these learning cycles in science education suggests that in order for students to experience science, they must first engage. But teachers struggled and one queried:

How do you keep people engaged when they're at home on their Chromebooks?
You know, hiding in their bed or in their closets, and they can only stay on for ten minutes because their bandwidth is so low that they can't use the Internet...so yeah, definitely the engagement factor went way down (P5).

Other teachers shared similar frustrations which I also experienced when teaching remotely in the 2020 spring term, and pointed out: “In a class of 25 or 30 kids, a core five or six would be

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

online and engaged, where the rest of them, their icon was on the screen, but were they actually there?" (P9); "Kids could have turned on their computer and went back to bed" (P8); and,

Talking to a screen, you have no idea what the kids' level of engagement really is... numerous times you would ask questions, and there would be no response.

So, you didn't know if they were sleeping or out of the room, or if they had caught what you were trying to communicate at that moment in time (P4).

Another teacher explained, "Because students knew videos were going to be recorded, we don't know if they were engaged in the lessons themselves" (P3). With student engagement greatly reduced during periods of remote learning when practical learning was restricted, the teachers were concerned with their overall ability to teach science effectively. Conveying significant frustration with their inability to engage their students, most aligned with one teacher who articulated:

During the pandemic *all* those hands-on things got dropped, it's just that rote learning, and not that experience, right. But how do you apply this... the stuff we need to do more of that is super important, just even in terms of engagement, and application. But that's what really got dropped and lost (P1).

Scholars such as Tal (2013) contend that practicing and applying authentic science in meaningful contexts fosters student engagement through cognitive, affective and social aspects to promote functional scientific literacy. Although teachers worldwide reported a need to bolster student engagement during the pandemic (Reimers & Schleicher, 2020), as one participating teacher emphasized, "Kids who really needed that hands-on, and even the social interaction with discussions" (P10) were not afforded opportunity. "Science engagement involves taking risks, spontaneity, motivation, and creative action" according to Valladares (2021, p. 567), but teachers

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

didn't even know if their students were tuned in during online instruction. Yet, they tried their best to engage students, as one described during a hybrid period with some in-class learning:

I created a project during the pandemic for the students to do, when they were able to engage with each other because they had to get their data from their classmates... it was interesting for them, because then they were actually engaging with their classmates (P3).

From my experience, while Grades 9 and 10 science teachers value student cooperative work to promote the development of important conceptual understandings, skills and attitudes in many curricular LOs, as scientific comprehension and reasoning skills are known to improve through experiential engagement (Beauchamp et al., 2021); they also value its positive influence on student engagement and overall importance for scientific literacy. Moreover, PBL and PBE scholars suggest placing students in the center of the learning process where they can engage in science practice, is key to developing scientific literacy (Crujeiras-Pérez & Jiménez-Aleixandre, 2017; Kim et al., 2019). This seems to have been the result of this participating teacher's small project. As student engagement remains central to the enduring definition of scientific literacy in science education discourse, partnered with meaningful learning, and context-driven, relevant student-centered activities (Loughran, 2011), the few opportunities afforded to students for interactive learning during the pandemic, were likely invaluable. Another teacher described creatively adapting practical learning activities to engage students whenever opportunity allowed:

During the pandemic... I had the Grade 10s do a design project... and they had to design a car. We actually had races and the kids loved it, like they absolutely *loved* it! I had a couple of students in particular who were just so checked out.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

And then when they were actually doing something, they'd get involved in the discussion and were coming up with ideas and thoughts that were great... and this is why we need to be doing this because some of these kids need it! Like they *need* it! (P3).

Hong et al. (2018) contend that science education should foster a student-centered learning atmosphere and promote experiential learning through design-oriented or project-based tasks; and as this teacher emphatically pointed out, Grades 9 and 10 students need such learning experiences—not only to develop technological problem-solving skills and attitudes (MEY, 2003), but to engage in their learning. Petersen and Kolb (2018) inform that “learning is present in every life experience and is an invitation to be engaged in each experience” (p. 230) and while experiencing [science] is the source of learning [science], the kinesthetic elements of design and competition excited students to engage in this learning activity. As science educators introduce new technical and procedural skill-building experiences, student thinking extends beyond cognitive operations and scientific concepts, greater understanding of science is achieved, and scientific literacy is advanced (Allchin, 2014; Croce & Firestone, 2020; Hodson, 2014).

While these teachers described some success engaging students in their learning, most of the teachers shared concerns with student engagement throughout the interviews:

I feel like kids have become disconnected with their learning. I think, because they became more isolated. A number of kids struggled with attendance, because it became very easy to fall off the grid... so I think that caused a greater number of kids to not connect with school, for sure (P5);

and, “When they were all isolated, I know a lot of the kids said to me, *I just don't care* about anything anymore... so they just kinda lost some, some will there” (P2). According to scholars,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

students disengaged from schools, disconnected with their learning, and scientific literacy was hindered during the pandemic as distractions and anxiety increased, and motivation decreased (Driessen et al., 2020; Gillis & Krull, 2020; Reimers, 2022). The overwhelming loss of interest and resulting impacts were validated by Valladares (2021), who explained that “science engagement is a multidimensional concept that comprises, at least, three components: (a) The behavioral, which refers to participation in science or science-related activities, both formally and informally; (b) the emotional, which embraces (positive or negative) affective responses to science, but also attitudes in science, including interest, boredom, happiness, sadness, and anxiety; (c) the cognitive, related to the extent to which students are willing to develop science concepts and skills, their motivation, self-regulation, and their interest and investment in learning and schooling” (p. 567). Without practical work, students’ behaviors changed, as many lost the motivation to participate; attitudes changed, as some lost the excitement of doing science and were bored; and some likely did not advance cognitively when uninvested in alternative learning activities requiring them to mainly do paperwork and work independently.

With regard to assessment, Davies (2020) points out: “The research is clear. When students are involved in the classroom assessment process, they become more engaged in learning” (p. 55)—and as some of these teachers had invited their students to participate in the assessment process, perhaps engagement was enhanced in some cases. However, synchronous, remote, and independent learning activities during the pandemic generally reduced student engagement in science. One teacher offered their insights into the underscoring challenges:

I think that’s the hard part, right? The students still have to be willing to connect to it right. It’s what makes Grade 9 and Grade 10 science so tricky because you have to acknowledge that you have students in your class that are not interested

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

in science, and they're not destined to be scientists. The biggest question to me is always, are the students learning from this... and you have to know them well enough to try and pique their interest, but certainly, if it's remote learning you don't get that opportunity (P10).

As students come from a variety of backgrounds and bring different approaches to thinking and learning along with diverse knowledge and experience, "it is important for teachers to activate prior knowledge [and to] encourage students to relate new information to prior experiences" (MET, 2000, p. 3). However, whether or not students arrived in Grade 9 or 10 science with relatable knowledge and experiences, the teachers stressed practical work as a necessary component to pique student interest and learning in science, as students are "more engaged when they're actually doing something" (P9); and moreover, "for some of those students less engaged, unless you were doing something hands-on, those students probably got a lot less out of it" (P10). While the Manitoba science curriculum documents indicate "a science education that strives for scientific literacy must engage students in answering questions, solving problems, and making decisions" (MET, 2000, p. 9), post-secondary scholars reported that students in STEM courses had great difficulty engaging in these processes during remote learning (Chen et al., 2020). Additionally, although engagement in hands-on manipulation of materials and equipment is vital to learning chemistry for instance (Chen, 2022), and experiential engagement is paramount to grasping the nature of science and critical thinking of authentic scientific practice (Watts et al., 2022)—when unattainable in remote Grades 9 and 10 science education, these teachers found that their students were disengaged.

As teachers continued to teach science while students were largely disengaged, one stated "I've reduced my expectations of students during the pandemic, because of the lack of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

engagement and consistency in their attendance” (P5). This is likely to have had unfortunate and considerable implications for their science learning. Moreover, “to achieve the vision of scientific literacy presented in the Manitoba science curriculum documents, students must become increasingly engaged in the planning, development, and evaluation of their own learning experiences” (MET, 2000, p. 4)—yet these teachers observed that most were less engaged, and some students did not attend or participate in online learning. Furthermore, these documents indicate ‘the development of scientific literacy is supported by instructional environments that engage students in scientific inquiry, technological problem solving, and decision making’ (MET, 2000, p. 4), but when teachers taught Grades 9 and 10 science with alternative learning activities that replaced practical work during the pandemic, students missed out on opportunities to engage in such instructional environments, arguably impacting the development of their scientific literacy.

While some Grades 9 and 10 science students were engaged in their learning and others were not, one teacher offered an important perspective: “I’ve never seen better and never seen more needs at the same time... the spread widened. A higher percentage of kids [were] struggling” (P5). Another teacher offered insights into this spread:

You have to split the students up into two groups. There were the students who are already academically motivated in science, and if they had to be at home, they were still completing all of their work, reading what needed to be read and watching when I was broadcasting. But then take the larger chunk of students who maybe weren't interested in science or interested in school in general, and they're not in the classroom, so they're not going to do anything at home. *Um!* Those kids would definitely be more affected (P1).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The perspective that students were either minimally or significantly impacted by their level of engagement during the pandemic suggests scientific literacy outcomes were variable for Manitoba students. Another teacher added to this discussion:

I think you can really tell the kids that are, *two years of nothing* compared to the kids that were engaged in doing a lot of things and probably might have benefitted from the fact that they were left on their own a little bit to explore and do things. I can teach a lesson now, and I've got kids that are like, yeah, I know all this already because I was reading a book or watching videos or doing stuff (P6).

I share this perspective, as when teaching Grades 9 and 10 science remotely in spring 2020 it became clear to me that students naturally fell into two groups: those who remained engaged in learning science through this mode of instruction, and those who did not. The enormous task of teaching science during the pandemic seemed difficult enough when students were invested in their learning; doing it when they were not was even more challenging.

While learning to teach in a remote environment and striving to maintain student engagement in learning when course grades and credits were previously assigned, Manitoba teachers required creative instructional approaches. As previously discussed, instructing Grades 9 and 10 science learners without practical work was challenging for these teachers, and they described alternative instructional strategies to foster student engagement in the remote environment such as: emphasizing topics of student interest; teaching LOs of lower cognitive value; assigning independent project options; incorporating various forms of student self-assessment; and inviting students to explore novel digital tools and programs in a variety of learning activities. While digi-pedagogy innovations helped some teachers to enhance

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

instructional design and prop student engagement during the pandemic (Lavonen & Salmela-Aro, 2021), despite their attempts with these and other diverse alternatives, the teachers interviewed were unable to engage some of their students. Coincident with an increase in inequitable student impacts confirmed in several OECD (Organisation for Economic Co-operation and Development) countries (Reimers, 2022), teachers globally faced similar challenges during pandemic periods of instruction and were unable to support the engagement of all learners, especially students with special needs (Lavonen & Salmela-Aro, 2021). While teachers' concerns for their students extended beyond their academic success during the pandemic (Audrain et al., 2021), these concerns were exacerbated when previously marginalized or vulnerable students were disengaged with learning science. One of the participant teachers seemed quite emotional when stating: "I lost a few students before the end of the school year [2020]. They had other things going on in their lives that took precedence" (P3). As Valladares (2021) explained, when students engage in learning science, they can develop a more intense relationship with science in their everyday lives, which can in turn foster personal and collective agency to apply scientific knowledge to cope with the challenges of the 21st century. It seems highly likely that when students do not engage in learning science, functional scientific literacy cannot be achieved, and they are ill-equipped for these challenges.

As Osborne and Pimentel (2022) contend formal science education cannot provide students with all the knowledge they require to evaluate science that is yet to come or future challenges not yet conceived, the loss of appropriate learning opportunities and resulting student disengagement meant enduring impacts for some: "Some kids who would have become more interested in science and maybe tried to go on in it, just kind of lost interest" (P5). The potential implications of ongoing disengagement in science to the development of student scientific

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

literacy are substantial, as Valladares (2021) explains that students who engage with science are more invested in discovering and participating in scientific processes and issues; and experience increased motivation to take action and creative agency. Furthermore, when student engagement promotes action to mitigate relevant SSI, science is humanized, and students have opportunity to think critically about science as they “deal with scientific experience in a complex society” (Valladares, 2021, p. 568). However, during the pandemic, these teachers learned such outcomes were not possible, as some in-person activities have no parallel online for engagement.

As inequities increased for all students during the pandemic, teachers' concern for academically motivated students were voiced when routine opportunities to extend science learning beyond their Grade 9 and Grade 10 courses were lost. Opportunities for science enrichment through a lunch hour environmental science club, and after-school opportunities to pursue research projects with scientific mentors were unavailable during the pandemic. One teacher stated: “My super keen and engaged science kids kinda lost momentum when that stuff disappeared, and I’m not sure they had the chance to pick that up again” (P2). I can relate to this teacher’s perspective from my pandemic teaching experience, when my 32 science students involved in off-site scientific research were unable to finalize their projects and compete in the Manitoba Schools Science Symposium which was cancelled in spring 2020. While most of these students were engaged with professional scientists or research mentors and on a trajectory to continue innovative scientific research throughout their high school years, none were afforded this opportunity. When authentic science learning opportunities routinely provided by some Grades 9 and 10 teachers to enrich science learning beyond the classroom came to an abrupt stop, it seems likely some students lives and future options were impacted.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Moving forward from the COVID-19 pandemic with a lens on the breadth of student impacts, one teacher reported:

Kids who really, really needed to be in school, like they missed their peers, they missed being in the building, I can now see them more engaged with school community and wanting to be here, and happier to be here (P5).

While noting increased student engagement and benefits to well-being with a return to in-person schooling, another teacher offered a contrary view:

Now that kids are back in the classroom, what I'm seeing as the biggest hurdle is kids re-engaging in full time learning where they have to focus. And I certainly say it impacted their practical learning extensively (P10).

This teacher's perspective that student disengagement during the pandemic resulting from the lack of practical work to learn science imposed an ongoing impact to future engagement—suggests the potential implications for student development of scientific literacy might extend beyond the defined pandemic period.

Theme Seven: These teachers perceived student learning gaps resulted from limited opportunity to learn science through alternatives to practical work during the pandemic; and perceived scientific literacy gains for Grade 9 and 10 students were inferior to those previously achieved.

Teachers described the impacts of pandemic restrictions on practical work they value for teaching science to center on two key factors aligning with the relevant scholarly literature: the elimination of authentic experiential learning opportunities that are crucial to engage Grade 9 and 10 science students in their learning; and the loss of student co-operative learning opportunities which critically support practical learning in science. The potential implications of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

each on student development of scientific literacy during the pandemic are in themselves prominent, but together, I think they are of striking concern.

“It had an impact *for sure*” (P3) one teacher crisply replied when asked about the loss of practical work on the overall development of student scientific literacy during the COVID-19 pandemic. As these teachers offered their account of observable gaps in the development of student scientific conceptual understandings, procedural knowledge, and attitudes during the pandemic, all expressed disappointment with their ability to advance student scientific literacy to a comparable level achieved pre-pandemic. During the pandemic, scholars found that teachers had difficulty advancing functional scientific literacy across all levels of school science throughout COVID-19 (Maia et al., 2021). The data I gathered suggests that the functional scientific literacy of students in these teachers' classrooms was also impacted. The science education scholarship conveys that scientific literacy is impacted when practical learning opportunities are restricted (Babinčáková & Bernard, 2020; Yan et al., 2021). One teacher, emphasizing a common pandemic teaching experience stated: “Lab work was non-existent, and students suffered from that because they didn't get that hands-on experience *at all*” (P7). Scholars have stressed the magnitude of impact on students' learning when practical work is missing (e.g., Patra et al., 2021); and the three kinds of learning Hodson (1993) proposed that science brings about: enhanced conceptual understanding; enhanced procedural knowledge; and enhanced investigative expertise were conjointly impacted when students missed out on hands-on learning. One teacher shared the view that:

I think probably the biggest thing is that their skills are not there. For example, last year, when I had Grade 11 chemistry, the kids were not at the level that I normally have them... they didn't have all of the lab skills. By Grade 11 and 12,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

I expect that they know how to use a graduated cylinder correctly to measure things, and all the different equipment. But they didn't really have an opportunity to do much experimenting (P2).

These Grade 9 and 10 science teachers, like myself, observed how restrictions to practical learning in Grades 9 and 10 science negatively impacted students' ability to learn science—most prominently in the development of procedural knowledge. Using a graduated cylinder is a basic lab skill that Grade 9 and 10 science students should learn, and one that most achieve with significant opportunity to practice in the Grade 9 Atoms and Elements cluster and Grade 10 Chemistry in Action cluster. Before the pandemic I had routinely noticed many of my Grade 9 students showing proficiency applying this skill in lab work at the start of each course. But with practical work restricted during the pandemic, I was not surprised when students entering Grade 9 or 10 science (after learning science in earlier grades during the pandemic) arrived with fewer skills, and deficits in their procedural and conceptual knowledge. Thus, some Grade 9 and 10 teachers were in a starting position with new students unlike previous years, where catch-up was required before they could begin to teach the concepts, skills and attitudes within the course. This experience is consistent with the literature. For instance, a 2022 study by Chen showed that technical skills were marginally attained through remote learning during the pandemic; while other scholars reported alternative remote approaches to practical work could not provide adequate learning activities for practical skills (Chadwick & McLoughlin, 2021; Rossettini et al., 2021). If the Grades 9 and 10 students began their science course with an inadequate skill base from earlier grades, being taught through alternative learning activities had the potential to significantly exacerbate these deficits.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

As noted, while the Manitoba high school science curricula are concerned with students acquiring knowledge, the standards are also concerned with the development of skills and with effecting a change of attitude (MET, 2000; MEY, 2003). Data from this study suggests that many scientific skills and attitudes were unattainable through remote instruction. As previously shown, teachers could not teach some of the foundational GLOs such as “demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind”; or “work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities” (MET, 2000, pp. 9-12; MEY, 2003, pp. 9-13); nor could they teach some Cluster 0 Overall Skills and Attitudes such as “carry out procedures that comprise a fair test”; “work cooperatively with group members”; “demonstrate confidence in their ability to carry out investigations in science”; or “demonstrate personal involvement and be proactive” (MET, 2000, pp. 0.3-0.7; MEY, 2003, pp. 0.3-0.7). However, as one of the participating teachers pointed out, “Hands-on experimentation as well as group work, that social aspect of doing experiments together and helping each other out... was lost” (P10). Scholars like Hodson (1993) contend that scientific practice is socially constructed, and when student participation and the development of scientific literacy are compromised many critical collaborative skills are unattainable. One teacher reported:

They [students] lost out on a lot of knowledge that they're now having to catch up on. Like learning Grade 12 biology without even knowing the basics from Grade 9. We're seeing *a lot* of those kinds of issues surfacing, a lack of collaboration skills... there has been a huge disconnect in their education, unfortunately (P9).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Science teachers such as this one recognized that the critical collaborative element of doing science that accompanies practical work and is prominent in the science education literature, is irreplaceable. As Natale et al. (2021) suggested, when teachers replaced practical and student cooperative work during the pandemic with alternative learning activities to keep staff and students safe, the impacts on learning were expected to be complex. One science teacher proposed that alternative forms of instruction meant “Many skills were not acquired because there were a lot of teacher-led discussions” (P7). Although Anderson et al. (2021) reported many teachers were able to successfully create new learning activities to replace traditional ones while emphasizing increased participation and collaboration, these Grades 9 and 10 science teachers were less able to do so when practical, collaborative learning opportunities were restricted. Other teachers added: “I have kids that have so very little knowledge, and they struggle with being independent” (P5); “Definitely now, during the pandemic there’s less of an ability of independent work... I find that [students] are less confident and require, many more frequent check-ins” (P2); and “They really struggle with any type of schoolwork at home. Literacy has gone down...also that ‘stick-with-it-ness’, the kids are a little bit more discouraged” (P9). As Natale et al. suggested, the impacts were indeed complex, as student interactive and independent skillsets were both compromised. Another teacher stressed:

We need to help students develop independence so they're not answering questions that should be pretty common for Grade 9s to know about - how to use a tool, how to take a measurement, how to write a comprehensive response based off of a hypothesis that you would develop from your lecture notes (P1).

Teacher observations of inferior skills and attitudes align with the general view found in the scholarly literature that student confidence and independence suffered when practical subjects

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

were taught remotely during the pandemic (Kochhar et al., 2022), and that online learning might deprive students of independent thinking (Dong et al., 2020). Without opportunities to teach many LOs requiring experiential and active learning where students are doing things, thinking about what they are doing, and communicating their thinking (Robertson, 2018), teachers indicated that they were less able to advance scientific literacy skills and attitudes as they had been able to prior to the pandemic.

While clear that learning science through alternative methods impacted the development of student skills and attitudes, the teachers also shared a common perspective regarding impacts to the acquisition of conceptual knowledge. The importance of practical work for learning science concepts was emphasized in their comments: “During the pandemic students suffered... they might have had gaps, or they still learned the content but it didn’t really sink in as much as when they would do a follow-up lab” (P10);

I feel like the students didn’t get as much out of it, like I don’t know if they’re going to retain as much versus if they learned about the topic I was teaching, and then did something hands-on with it. They’re going to remember doing that hands-on thing, and then they’re more likely to understand the concept (P9);

And,

It would be a bit of an understatement to say learning did not suffer... without the practical component it’s hard to say how much *actually stuck*. I just don’t think they’re going to retain as many of the concepts if they didn’t have some sort of practical work that they did with it, after learning about it (P1).

These teachers’ views that their students suffered and were left with conceptual gaps when learning science without practical work shadow scholars’ beliefs that greater understanding of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

science is achieved when technical and procedural skills are developed through hands-on laboratory experience (Ożadowicz, 2020), as experiential engagement improves scientific comprehension and reasoning skills (Beauchamp et al., 2021; Yang et al, 2021). While studies comparing experiential learning to lecture based learning in STEM courses confirmed that hands-on learning positively correlates with enhanced academic achievement (Anderson et al., 2020; Cohen Zilka, 2021), the teachers interviewed corroborated, noting the absence of hands-on learning correlates with decreased academic achievement: “I would say they are a lot weaker, academically” (P7). Other teachers added, “I think that they have declined in their overall achievement, because a lot of the retention and knowledge that I’m seeing in older kids is not where I would expect them to be” (P3); and,

While alternate learning activities, helped a little bit... it was certainly not to the extent they would have got with hands-on learning. And so, seeing what a lot of my Grade 9s and 10s are trying to accomplish in Grade 11 and 12, you get to see a lot of gaps, and you're teaching them things that you would have hoped that they would have learned in Grade 9.... There's definitely some consequences (P1).

Evidence to support these consequences might be found in the 2022 Programme for International Student Assessment (PISA) scores for 15-year-old students in the domain of science (Huillery, 2025). While the core domain assessed by PISA 2022 was math, data for science was also collected from 29 million students in 81 participating OECD countries (Crato & Patrinos, 2025). PISA provides strong evidence that learning losses from the pandemic exist across multiple grade levels, and although these varied globally, students in most OECD countries underperformed in science (Gajderowicz & Jakubowski, 2025; Huillery, 2025). While Tire

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

(2025) describes a downward trend in the domain of science for students in Estonia, Herrera-Pavo et al. (2025) describe notable setbacks in science for Grade 10 students in Ecuador while emphasizing physics concepts such as position, direction, and speed—Grade 10 science concepts also taught in the Manitoba In Motion cluster. Furthermore, Oates (2025) pointed out that for students aged 13-14 who experienced learning loss caused by interrupted learning in England during the height of the pandemic in 2020-2021, the impact was distinctive. As Manitoba Grades 9 and 10 students of comparable age learned comparable science concepts with other students internationally during the pandemic, the distinctive impacts described by the participant teachers in this study might align with observations of teachers worldwide. It is interesting that most nations including Canada and the US saw student achievement in science as measured by PISA 2022 fall below pre-pandemic levels, but while US students performed poorly, Canadian students ranked seventh among the 81 participating countries (Hanushek & Strauss, 2025).

Kuhfeld et al. (2022) reported educational consensus that the pandemic had negatively impacted student achievement but that the ultimate effects and impacts of the pandemic disruption to learning are difficult to ascertain. Kuhfeld et al.'s proposal that student performance might reflect the loss of curricular content and learning opportunities resulting from school disruptions, aligns with observations of teachers interviewed in this study and their concern for ensuing student impacts. While estimates of the decline in student academic achievement from various countries range from minimal effects to a full year of educational setbacks (Gajderowicz & Jakubowski, 2025), Reimers (2022) confirms complex and unknown consequences for students, and their potential for educational attainment following learning losses in knowledge and skills during COVID-19. According to one participant teacher, "It could be like a half-generational impact while we wait for all the kids to get caught up for the two and a half years

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

that they missed out” (P10), corroborating Oates (2025) suggestion that for students in England, this means carrying some degree and form of pandemic impact throughout the rest of their schooling, to the mid-2030s.

For Manitoba students enrolled in the next levels of science, deficits in conceptual understanding from learning science through alternative approaches in Grades 9 and 10 when practical work was restricted meant catch-up work was required. All participating teachers expressed this view. One stated, “I’ve got some kids in my Grade 12 biology class who did their Grade 9 or Grade 10 biology, and don’t really have anything, it wasn’t covered. Or they didn’t get it ... I am seeing some gaps in the higher levels” (P2). Another teacher explained,

I was able to see this afterwards, because I’m teaching Grade 11 chemistry and physics. I think the performance during the pandemic suffered, and consequently also suffered for the higher, Grade 11 and 12 science courses for the students that continued on with those, not just based on content, but basic skills and abilities too. Yeah, definitely suffered. I would say critical thinking. You can see it in their abilities now in the higher-level sciences (P5).

Collectively, as these teachers revealed the significant breadth of student learning gaps, their views were echoed by others: “Through the pandemic, yeah, I would say that all [problem solving, critical thinking or decision-making abilities] got quite a bit worse” (P10). As scholars and science teachers alike appreciate that functional scientific literacy is continuously developed, in small steps through the interconnection of critical thinking, self-awareness-raising, critical positioning, and decision-making (Allchin, 2014; Almeida et al., 2022), observable setbacks in the development of scientific literacy skills in Grades 9 and 10 were concerning.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Most of the teachers centered the interview discourse on student learning impacts for those in pursuit of higher levels of science, while fewer focused on impacts for those ending their formal science education in Grade 10. Numerous concerns about the next steps in science were voiced:

They [students] just had a two-year mental break in a way where they weren't using their brains the same way as they always did, and I think we can't expect the same level of performance right away that we would have seen, and I think it's going to take a couple years (P1);

“Students have *lost two years plus* of science learning, right? They don't know how to ask questions or investigate and experiment the same way they used to” (P4); and “I think there are going to be a lot of disadvantaged students going forward over the next few years, just because of what the pandemic has done to science education, unfortunately” (P8). The teachers were clear—they felt that learning science during the pandemic resulted in student gaps in scientific conceptual knowledge, procedural skills and attitudes they consider important to success in higher levels of science. While Crato and Patrinos (2025) propose some cognitive losses are difficult to regain, two experienced science teachers suggested,

Many students do want to take higher-level sciences or they had the intention of taking higher level sciences before the pandemic. I'd say about half would get through okay, and be able to either catch up or learn independently (P9);
and,

I would say it's definitely hindered it a little bit but didn't completely cause all students to suffer.... Some students studied on their own or were good at

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

studying on their own in the first place, or maybe they were great at catching up (P7).

As the teachers of higher-level science courses observed substantial gaps in student knowledge despite their extensive efforts to provide effective alternative instruction in Grades 9 and 10 science throughout the pandemic; it follows that students ending their high school science education in Grade 10 would be left with equivalent, or even greater gaps given their limited interest in pursuing science beyond Grade 10. Considering Valladares' (2021) perspective that scientific literacy is a gradual, measurable, discretionary concept, the impact of an inadequate end to learning critical scientific literacy competencies cannot be measured. Developing functional scientific literacy during the final two years of mandated science learning in Manitoba is a particularly opportune period of time for all students; but for students ending their formal science education at this stage during the pandemic, perhaps a final opportunity lost. Gonçalves and Capucha (2020) had reported the cessation or postponement of hands-on learning during COVID-19 to be responsible for major irreversible losses in learning, and as the teachers pointed out: "A lot of our Grade 10s have chosen not to take any more science classes" (P3); "The kids that were done at the end of Grade 10, they're definitely missing some of the evaluation of day-to-day science, like being able to read the newspaper and understand what's going on" (P5), and,

I know, Grade 10 science is the last time you could take science, but I mean, the fact is that science exists around us all the time, and even if it's not the topic that's of interest to you for university, there are still those skills and attitudes that are important to everyday life (P10).

While the Manitoba science curriculum documents direct that science education will provide students with "a proficiency in science that creates opportunities for them to pursue

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

progressively higher levels of study to prepare them for science-related occupations; [and] develop in students of varying aptitudes and interests a knowledge of the wide variety of careers related to science, technology, and the environment"; they also direct teachers to: encourage students at all grades to develop a critical sense of wonder and curiosity about scientific and technological endeavours; enable students to use science and technology to acquire new knowledge and solve problems so that they may improve the quality of their own lives and the lives of others; prepare students to critically address science-related societal, economic, ethical, and environmental issues; and to create opportunities to engage [students] in science-related hobbies appropriate to their interests and abilities (MET, 2000). Moreover, as the vision for scientific literacy in the documents indicates diverse learning experiences are required to "provide students with many opportunities to explore, analyze, evaluate, synthesize, appreciate, and understand the interrelationships among science, technology, society, and the environment that will affect their personal lives, careers, and their future" (MET, 2000, p. 2), many lifelong skills and attitudes are typically developed in Grades 9 and 10 science. Of little surprise, Heng et al. (2022) found that study during COVID-19 may disadvantage students when compared with a 'normal' education, as experiences with scientific inquiry, technological problem solving and decision making that are required for students to consider the significance of science in their lives, were drastically limited during the pandemic. Yet, Price and McNeill (2013) contend students require functional scientific literacy to live and function in today's world; and to make informed and personal decisions on societal issues that science education scholars such as Maia et al. (2021), Natale et al. (2021), and Osborne and Pimentel (2022) believe all students should be equipped to understand. One of the teachers however, shared the view, "If they're going to go on into a trade or something practical or have other plans after graduation, then I don't think in

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the grand scheme of things it's going to make a big difference in their life" (P3). From my perspective, if students miss out on learning critical attitudes and skills to evaluate scientific issues in society and in their personal lives, such as making informed choices regarding their own vaccinations for instance, the impacts might be great regardless of their future employment plans. In order for students to learn how to live meaningful lives and careers and participate actively in society as functionally scientific literate citizens, they require learning opportunities to relate and apply their scientific knowledge in their everyday lives (MET, 2000)—a point accentuated by Suardana et al., 2018, Bencze et al., 2020, Maia et al., 2021, among others.

During the pandemic, the teachers were clear: "I would say, the students who did Grade 9 and 10 science pre-pandemic were more scientifically literate than those that are doing 9 and 10 during, or since" (P11). Aligned with Hanushek and Strauss (2025) who are doubtful that the average student did better than they might have without the pandemic, all of the teachers shared a similar perspective:

There are definitely way more gaps that exist... if you were to take a look at the kids that are graduating this year [June, 2023] that were in Grade 9 at the start of the pandemic, I don't believe that they have the full set of skills and knowledge that a typical kid would have (P2).

While assessing their students, these teachers bared the critical element scholars emphasize as crucial for learning science—that in order to learn science, students need to experience science (e.g., Agarkar, 2019; Withers & Schinske, 2016; Yang et al., 2021). Moreover, scientific literacy is best achieved when students have authentic opportunities to unite conceptual and procedural knowledge as scientists do (Hodson, 1993); to conduct research, practice skills, think critically and reflectively, and to make higher order decisions (Duran et al., 2016); and to develop a more

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

intense relationship with science that Valladares (2021) suggests is necessary to cope with everyday life and the challenges of the 21st century. However, without these authentic opportunities during the pandemic, deficiencies in a variety of important elements required for functional scientific literacy might directly influence the ability of students who were in Grades 9 and 10 during the pandemic to critically navigate science and technology in their lives; claims made by scientists, governments and organizations; and scientific issues reported in the media, for an ongoing but undetermined period of time. Furthermore, according to one teacher,

If we're trying to put a bunch of people out there that have general science knowledge, so they know how to function in society and understand climate change and that Earth is a sphere and not flat, and we're trying to suggest that society should know better, well then, we need to be making sure that our science education system reflects that (P10).

Two other teachers emphasized, “There’s a lot of information out there, and I think critical questioning is more important now than it's ever been” (P5); and “The urgency of rediscovering science is there” (P4). As revealed throughout the interview discourse however, while the Grades 9 and 10 science teachers adjusted their programs with creative agency, alternatives to practical work did not provide them opportunity to effectively advance scientific literacy. Yet, while embracing their professional goal to provide an effective learning environment for students to develop scientific literacy concepts, skills and attitudes; the teachers acknowledged its secondary ranking to their role as professional caring educators of Grades 9 and 10 students experiencing the COVID-19 pandemic:

At the start of the pandemic, it was very hard to have any expectation for any sort of scientific literacy. I can model it. I can talk about its importance. But

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

there was just so much other stuff going on in the world and around them and in their families... it was really hard to say this is the number one thing you should be worried about, like that was really hard (P1).

In summary, although the pedagogical priorities of Manitoba Grades 9 and 10 science teachers extend beyond the scope of this study, the Phase II data offered significant insights into the perceptions and beliefs grounding their efforts to teach science and to advance student scientific literacy during the pandemic. Moreover, the findings suggest that the performance and achievement of Grades 9 and 10 science students were significantly impacted by numerous barriers limiting the teachers' ability to advance scientific literacy, most notably the loss of practical, collaborative work—which likely resulted in inferior scientific literacy outcomes for students compared with those observed pre-pandemic.

Summary of Phase II Findings

The Phase II interview data was helpful to expand and explain the Phase I survey data, and to address the Phase II research questions and main research question guiding this study.

Initial analysis of the Phase II data led to the development of 38 codes and six code groups (see Appendix E), four sub-categories, and three descriptive categories: Factors underpinning the priorities of Manitoba Grade 9 and Grade 10 science teachers' curricular content and approaches during the COVID-19 pandemic; Dynamics of teaching Grade 9 and Grade 10 science during the COVID-19 pandemic; Perceived learning impacts for Grade 9 and Grade 10 science students during the COVID-19 pandemic. Seven themes were established from the interconnections identified between the three categories and were used to guide the Phase II analysis to address the Phase II research questions.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Data from the Phase II interviews revealed that these teachers' personal and professional lived experiences guided their pedagogical decisions regarding what and how to teach their students, and their experiences teaching Grade 9 and Grade 10 science prior to and during the pandemic were extremely different. Teachers highlighted numerous challenges accompanying the sudden shift to remote teaching while emphasizing difficulties associated with new technologies required to teach remotely that hindered their ability to teach science. Teachers also stressed the dramatic shift in science pedagogy to teacher-centered instruction amid restrictions to practical work, which intensified their workload and struggles to elicit and maintain student engagement. These challenges were ongoing for teachers, however frequent changes throughout different pandemic periods and instructional modes complicated their decision-making regarding what to teach, and how to teach it.

Teachers described a necessary shift in priorities during the pandemic to teach fewer units and LOs to their students, and to modify learning expectations when restrictions limited their ability to teach their usual programs through practical and collaborative student learning activities. Unit and LO teaching priorities remained centered on the three key sciences: chemistry, biology and physics, which teachers generally perceive as most important to prepare students for higher levels in science, or for life; while content depth and breadth were significantly reduced. Grade 9 teachers that were interviewed mainly prioritized two units: Atoms and Elements, and Reproduction, while fewer prioritized Nature of Electricity and most minimized or omitted Exploring the Universe. Grade 10 teachers that were interviewed mainly prioritized the Chemistry in Action and In Motion units, while fewer prioritized Dynamics of Ecosystems and the Weather Dynamics unit was minimized or omitted by most. During the pandemic teachers generally taught fewer unit SLOs overall, mainly due to restrictions limiting

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

student contact time and practical, collaborative learning; and notably prioritized unit SLOs over the GLOs and Cluster 0 Skills and Attitudes SLOs. Other influences contributing to the shift in teaching priorities included issues with technology and Internet access; the need to adjust learning expectations and to prepare students for their next levels in science; school or team decisions about curricula, instruction and common exams; and safety issues for staff and students. Consequently, what teachers chose to teach, or not to teach during the pandemic significantly impacted their ability to promote some of the foundational concepts, skills and attitudes in Grades 9 and 10 science that are required to advance functional scientific literacy.

While exceptionally constrained by pandemic protocols restricting the practical, collaborative work they value as central to their practice in Grade 9 and 10 science, in addition to what they taught, teachers adjusted how they taught. These teachers adjusted their instruction and assessment in various ways to continue teaching the scientific concepts, skills and attitudes in the science curricula to their students throughout the pandemic. While developing and implementing a variety of alternative science learning activities, teachers embraced an increased use of digital resources - videos, simulations, and specific educational websites such as PhET, Edpuzzle and ExploreLearning; along with online scavenger hunts, independent projects and paperwork, and independent practical learning activities whenever possible. Overall, these Manitoba teachers found ways to ensure their students continued to learn science when practical and collaborative work were restricted during the pandemic, even though they could not teach all of the units or LOs they prioritized in their courses. Yet, despite their professional dedication and creative determination to teach scientific competencies through alternative approaches replacing restricted practical work, participating teachers observed that Grade 9 and 10 students were less engaged in their learning without opportunities for hands-on practice.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Although these teachers were challenged to adequately assess student learning during the pandemic, perceived learning gaps resulting from limited opportunity to learn science with practical work during the pandemic were observed and reported, and scientific literacy gains for Grades 9 and 10 students were perceived as inferior to those previously achieved. Consequently, these teachers believe some students might require remedial supports in higher-level science courses to address gaps in procedural or conceptual knowledge; while others might encounter disadvantages in daily life from practical and collaborative opportunities lost to adequately develop functional scientific literacy. Some perceived benefits of pandemic learning however, include increased student independence in some cases, and enhanced digital skills for some students.

Integrated Analysis of Phase I and Phase II

How curricular content and approaches prioritized by Manitoba Grade 9 and 10 science teachers during the COVID-19 pandemic impacted their potential to advance student scientific literacy was answered through both phases of research and the integrated analysis I conducted. The integration of the quantitative and qualitative phases allowed me to identify insights extending beyond the results of each phase, and as described in Chapter 3, is necessary in mixed methods analysis to develop more complex understandings and conclusions to the research problem (Bazeley, 2018; Hesse-Biber & Johnson, 2015). Such integration also aligns with the theoretical framework guiding my study, allowing a postpositivist lens for objective analysis of the Phase I data to unite with valuable subjectivity through multiple perspectives in the Phase II data to extend these understandings (Creswell & Poth, 2018; Young & Ryan, 2020). As human knowledge is conjectural (Lederman & Abell, 2014; Phillips & Burbules, 2000), integrating survey data with interview data not only allowed opportunity to address different specific sub-

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

questions to contribute to the understanding of the main research problem, but as postpositivist scholars such as Wildemuth (1993) suggest may occur, richly informed it.

I compared the Phase I and Phase II findings to find common concepts across both sets of findings, and to determine how results confirm, disconfirm or expand each other. Further interpretations of how the evidence enhanced understanding of and provided insights into the research problem, and how both sets of results together address the central research question are explained. The findings from each phase were organized into three groups for comparison, aligning with the research questions: First, curricular units and LOs prioritized in Grades 9 and 10 science prior to and during the COVID-19 pandemic; Second, LOs taught through practical work prior to the pandemic and those taught through alternate activities as teachers adjusted their pedagogy through school lockdowns and restrictions during the pandemic; Third, how teachers perceived alternatives to practical learning activities allowed them opportunity to effectively promote scientific literacy. Summary representative statements are presented to support the findings in each of the three groups.

First, analysis of the Phase I survey data revealed that prior to the pandemic a large proportion of responding Grade 9 and Grade 10 science teachers prioritized teaching four or three curricular units and their associated LO thoroughly; and that during the pandemic a notable shift to prioritize three units occurred, and some teachers were unable to teach the entirety of the three units. The majority of teachers prioritized and taught the chemistry unit and associated SLOs in Grade 9 and Grade 10 science both prior to and during the pandemic, and also ranked the biology and physics units and SLOs in each grade as a significant priority. The clusters and SLOs of lowest priority were in the fourth discipline, outside the three key science disciplines of biology, chemistry and physics. Strikingly, few participants taught the fourth clusters, Exploring

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

the Universe in Grade 9 science, and Weather Dynamics in Grade 10 science, prior to the pandemic and none taught these during the pandemic. The Phase I results also showed most teachers prioritized teaching the cluster SLOs, over GLOs or Cluster 0 SLOs both prior to and during the pandemic; with a notable decline in the proportion of teachers adequately exploring the Cluster 0 SLOs during the pandemic. These findings are relevant to the first Phase I sub-question and were confirmed and understandings extended in Phase II: teachers generally prioritized teaching unit SLOs over GLOs and Cluster 0 SLOs prior to, but more so during the pandemic. It was first found that the three foundational clusters in each of Grade 9 and Grade 10 science, specifically biology, chemistry and physics are considered vital for further study in these disciplines, and as such are a steadfast priority for many science teachers to effectively prepare their students for the next level—often resulting in limited instruction of the Grade 9 Exploring the Universe and Grade 10 Weather Dynamics units at best but more often in their omission. As such, some Manitoba students might leave high school with important scientific concepts of weather last learned in Grade 5 science, and space science concepts last learned in Grade 6 science. Given the prominence of these two disciplines to functional scientific literacy in the 21st century, where climate change and communication through space dominate our daily lives, student impacts of these teachers' decisions may be substantial. That said, it is important to acknowledge that students may learn some of these concepts outside of their formal schooling. Second, the Phase II results revealed that some teachers or teaching teams developed strategies to integrate course units and LOs in order to teach all four units and a greater number of LOs; while others eliminated the most complex LOs to maintain student attendance and engagement—meaning Manitoba students had variable opportunities to learn course units and LOs both prior to and during the pandemic. Third, while teachers did their best to teach as many units and LOs

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

through various modes of pandemic teaching and learning that included remote and BL, they could not teach as many units or LOs due to collective impacts that school structures, educational foundations, resources and personal experiences had on their pedagogical practice; but moreover, because practical and collaborative work required to teach many of the LOs in Grade 9 and 10 science were not possible.

Summary Representative Statements include:

- “The biggest hindrance to educating students during COVID when it came to Grade 9 and Grade 10 science was the fact that the government said right off the hop, their marks would not be important, and that made it really hard for teachers” (P1).
- “It [the pandemic] totally took my teaching philosophy and flipped it upside down” (P2).
- “Prior to the pandemic, I taught all four clusters in Grade 9 and Grade 10 sort of equally, while tying units together” (P7).
- “Prior to the pandemic, three out of four clusters would be covered in both Grades 9 and 10. The Universe is omitted in Grade 9, and in Grade 10 we all omit the Weather unit, because if you want to provide enriched lessons with labs and activities, there’s no possible way to get to all four units” (P3).
- “I would have to say the focus was on those key three, the physics, the biology, and the chemistry... we placed greater emphasis on prerequisites or things that are required for further study in either high school or even university” (P10).
- “I would more so emphasize the essential outcomes or important outcomes that are needed for moving forward, either because they were cumulative in the subject itself at that grade level or it was carried on to the following grade level” (P5).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- “During the pandemic, we had to cut some of the content so we just focused on physics, biology and chemistry... we did three units as opposed to four” (P9).
- “During the pandemic we emphasized the essential outcomes needed going forward, catering to the group of students that wanted to continue with science, but we ultimately disadvantaged those that didn’t want to continue with science” (P11).

Second, from the Phase I results it was clearly established that a large proportion of teachers taught a significant number of LOs through practical work prior to the pandemic; and overall, fewer teachers taught these LOs through alternate activities not practical in nature during the pandemic. Certain SLOs taught by many teachers through practical work prior to the pandemic continued however to be taught by a similarly large proportion of teachers through alternate means during the pandemic—which were found to either be SLOs of greater importance for Grades 9 and 10 science teachers, or those possible to teach without practical work. The Phase I findings further showed that Grade 9 and 10 teachers had a generally greater focus on teaching the GLOs and Cluster 0 Skills and Attitudes SLOs prior to, versus during the pandemic, many of which are significantly hinged on practical collaborative work to teach; and that all of the teachers believe practical learning opportunities are important for students to develop scientific literacy concepts, skills and attitudes but the large majority could not provide these to their students amidst pandemic restrictions. The Phase II findings confirmed those found in Phase I, while extending understandings into which LOs were taught through practical work prior to the pandemic; and ways that teachers adjusted instructional approaches to provide alternative learning activities to teach these LOs during the pandemic, answering the second Phase I and first Phase II research sub-questions. The Phase II findings suggest that some Manitoba Grades 9 and 10 science teachers normally teach science by providing students with

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

frequent opportunities for collaborative work and a wide variety of practical learning activities, which they emphasized in Phase I as necessary for students to learn scientific concepts, skills and attitudes. When lockdowns and restrictions prevented practical work and laboratory activities, these teachers sought, developed and implemented a variety of alternative science learning activities embracing an increased use of digital resources—yet despite their creative and determined agency, teachers were limited in teaching some Grade 9 and 10 science LOs that require practical work and experiential learning opportunities to achieve.

Summary Representative Statements include:

- “Prior to the pandemic, probably two to three times a week the kids were doing something like practical group work or a lab” (P8).
- “During the pandemic, laboratories or hands-on learning activities, *gone*” (P9).
- “Like try to teach somebody how to drive a car without actually getting them into the front seat” (P1).
- “Not being able to touch and manipulate, the kids are losing a lot of value in that type of learning and I had a very hard time trying to find anything that remotely compared” (P10).
- “I don’t know if I was doing a good sales job on how critical science is to us, when I was handcuffed” (P7).
- “They shifted from exploration and supervised investigation, to videos of *this is what we would have done*. This is what you *would have* participated in. But watch the video, you’ll get the gist of it... I don’t think it can *ever replace* the doing of something to accentuate or reinforce the theoretical learning” (P1).

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- “With desks six feet apart, plexiglass partitions and students wearing masks, labs turned into discussions and students just didn’t tune in (P6).
- “The buy in was not there. Reading a bunch of stuff is not the same as being able to experience it, and try it in a hands-on practical type way” (P2).
- “Talking to a screen, you have no idea what the kids’ level of engagement really is... numerous times you would ask questions, and there would be no response” (P4).
- “Hands-on experimentation as well as group work, that social aspect of doing experiments together and helping each other out, figuring out what went wrong or what worked... was lost” (P5).
- “Without resources and supports in place, it was absolutely like the blind leading the blind... trying to do the best that we could. We just bought supplies off of each other through [Teachers] Pay Teachers, or shared resources, or made stuff up at 11:30 at night ourselves!” (P2).
- “I used a lot of Edpuzzle and ExploreLearning... for having hands-on in science become digital, this was by far the best resource” (P1).
- “The pandemic opened up other ways to do hands-on learning, such as à la carte labs – individualized small-scale discovery-based labs where students were provided their own equipment at their desks and prompted to complete a discovery-based laboratory procedure” (P11).

Finally, how teachers perceived alternatives to practical learning activities allowed them opportunity to effectively promote scientific literacy were found indirectly in four of the Phase I survey questions, and relevant to the second Phase II research question. It was established from the responses to the Phase I questions that responding teachers generally perceived an adequate

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

ability to advance student scientific literacy, both prior to and during the pandemic. First, prior to the pandemic a large proportion of Grades 9 and 10 science teachers who answered the survey said they frequently engaged students in SI, debate about scientific issues or the design process to solve a technological problem—valuable activities for student development of functional scientific literacy (MET, 2000); and although fewer teachers engaged students in such learning activities during the pandemic, a sizable proportion indicated they were still able to do so. Second, a notable proportion of teachers indicated their students often had opportunity to work cooperatively with group members to plan an experiment, carry out the plan, and troubleshoot problems if they arise, during pandemic lockdowns and restrictions. Third, the large majority of responding teachers expressed some level of confidence in their ability to foster scientific literacy competencies during the pandemic while practical work was restricted. That said, these teachers may not be representative of all teachers, as those who felt they did a poor job during the pandemic may not have participated in the study. These three Phase I findings, collectively depict a perceived level of teacher confidence that alternative learning activities to practical work effectively allowed them to promote scientific literacy during the pandemic. This perception seems to counter other Phase I data however, where the majority of teachers indicated their students had infrequent or no opportunity to experiment, use data collection tools, make measurements, control variables, and/or use WHMIS regulations and safety equipment for instance; and was disconfirmed in comparison with the Phase II results. The Phase II participants had limited confidence in their ability to foster scientific literacy concepts, skills and attitudes during the pandemic while practical work was restricted, were unable to engage students in SI, debate or the design process, and their students did not have frequent opportunity to work cooperatively with group members when student-centered learning was replaced with teacher-

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

directed instruction. Finally, according to the Phase I findings and important to answering the second Phase I sub-question, prior to the pandemic a large proportion of teachers perceived being adequately able to explore 15 of 48 select Cluster 0 Overall Skills and Attitudes SLOs with their students; while during the pandemic an overall decline in teachers' perceived adequacy to explore a large number of these SLOs was reported. Although teacher capacity to adequately explore certain Cluster 0 SLOs promoting scientific attitudes was less impacted or even marginally improved during the pandemic in some instances, teacher capacity to adequately explore certain Cluster 0 SLOs for learning scientific procedural skills was significantly reduced. Since procedural skills require practice to attain, I infer the significant decline in teachers' perceived adequacy to explore Cluster 0 SLOs during the pandemic suggests perceived inadequacy of alternatives to practical learning activities to effectively teach these skills and thereby promote scientific literacy—which the Phase II interview findings confirm.

My integrated analysis also suggests that although teachers' pedagogical decisions were similarly influenced by school structure and educational foundations, the influence that resources and teacher experiences imposed on pedagogical decisions varied greatly between individual teachers. Consequently, varied teacher perceptions resulted for what it meant to effectively promote scientific literacy during the pandemic, while implementing alternative science learning activities not practical in nature. The Phase II findings revealed teachers were largely unsure of their ability to advance student scientific literacy during the pandemic, mainly because of barriers to practical learning, but also in part because of difficulties with implementing effective and reliable assessments of student performance and achievement. Yet, they were all in agreement that a distinct decline in student performance and achievement was apparent, and unavoidable gaps in student scientific conceptual understandings, procedural knowledge, and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

investigative expertise necessary to learn science were the result of restrictions in practical learning during the COVID-19 pandemic. This finding was generally consistent with conclusions found in other jurisdictions as reported in the literature (e.g., Borish et al., 2022; McKnight et al., 2022; Watts et al., 2022) among others. The Phase II findings reveal teachers perceived the decline in student performance and gaps in scientific literacy to vary among students throughout the pandemic, and increased teacher awareness of individual student needs.

Summary Representative Statements include:

- “Students suffered because they didn’t get that hands-on experience *at all*, and might have had gaps” (P7).
- “It would be a bit of an understatement to say learning did not suffer, because it’s easy to teach all those SLOs from a theoretical standpoint... but without the practical component it’s hard to say how much actually stuck” (P1).
- “Some kids rose to the occasion though because they had to, and other kids just *gave up*” (P9).
- “The pandemic forced independent opportunities, in that every kid had to learn skills that often, other group members took responsibility for” (P6).
- “Kids who really needed that hands-on... some kids who would have become more interested in science and maybe tried to go on in it, just kind of lost interest” (P5).
- “A lot of our Grade 10s have chosen not to take any more science classes” (P3).
- “There are definitely way more gaps that exist within the content. If you were to take a look at the kids that are graduating this year that were in Grade 9 at the start of the pandemic, I don’t believe they have the full set of skills and knowledge that a typical kid

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

would have. I also don't feel that they've had the same experiences either, to help them as learners" (P9).

- "The students who did Grades 9 and 10 science pre-pandemic were more scientifically literate than those that are doing 9 and 10 during, or since" (P11).
- "I think there are going to be a lot of disadvantaged students going forward over the next few years, just because of what the pandemic has done to science education, unfortunately" (P8).
- "Students have lost two years plus of science learning, right? They don't know how to ask questions or investigate and experiment the same way they used to" (P4).
- "It could be like a half-generational impact while we wait for all the kids to get caught up for the two and a half years that they missed out" (P10).

My analysis of the data in this study concluded with an integrated analysis of the Phase I and Phase II findings. Meaning found in the Phase II interviews propped development of early thematic conceptualization in Phase I analysis; and emergent themes resulting from the coded data, sub-categories and categories determined in Phase II were confirmed during integrated analysis. Finally, the main research question in this study: How do the curricular content and approaches prioritized by Manitoba Grade 9 and 10 science teachers during the COVID-19 pandemic impact their potential to advance student scientific literacy, was addressed.

Research Limitations

Limitations in this research included various issues of access to potential participants, similar to limitations described by Creswell and Poth (2018). As data for Phase I and Phase II of this study were reliant upon recruiting Grade 9 and Grade 10 teachers with time and willingness to participate while emerging from the COVID-19 pandemic, demands on teachers' time

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

remained exceptionally great and recruitment numbers may have been lower as a result.

Consequently, generalizability in this study is limited and some important insights might not have been collected. Moreover, teachers who felt more uncomfortable about the choices they made when teaching during the pandemic may have been less willing to respond to the survey than those with more experience or greater confidence in their pedagogy. This may have resulted in data not representative of the pedagogical practices of many Manitoba teachers.

Other factors that may have influenced the number of participants in this study included the sequence of permissions required for access to potential participants. Administrative permission was granted for teachers in 21 of the 38 school divisions in the province to participate. 11 rural school divisions did not respond to the invitation to participate however, and six superintendents did not allow their teachers to participate, reasoning educators were significantly burdened by the pandemic demands on their time. Additionally, since school divisions were required to distribute information and consent forms to teachers electronically, these documents may not have made their way to all of the Grade 9 and Grade 10 teachers in the division, for a myriad of different factors (emails sent to a junk folder, for example). Further limitations associated with data collection and the instruments may have included issues with SurveyMonkey survey access and function.

Intrinsic limitations to the instruments used in this study relate to the a posteriori nature of many of the questions asked in the survey and interview. For instance, the COVID-19 pandemic continued for over two years, and teachers were required to recall what they taught and how they taught prior to the pandemic. Although some were confident to answer questions from this period, some may have been unable to remember accurately, and some were unable to recall certain details. Furthermore, as teachers taught through two years since the pandemic began, with

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

shifts from remote teaching to blended teaching, to in-class learning, to remote teaching and back again to in-class learning, some were unable to clearly distinguish these periods of time in their Grade 9 and Grade 10 science classes.

Another limitation resides in the fact that teachers who responded to the Phase I survey may be teachers who are the most digitally proficient and as such may have been better equipped to respond to the shift to a remote learning mode, hence skewing results. Similarly, participants might be those with strong views on Grade 9 and Grade 10 science pedagogy, or with strong views on education during the pandemic in general, which could influence the nature of responses gathered. Likewise, misinterpretation of survey questions, respondent fatigue, and participants' current mood or unwillingness to report autonomous professional choices even in an anonymous survey may have influenced the data collected.

Finally, teachers who responded to the Phase II interviews were not selected as representative of the larger population of Grade 9 and 10 teachers in Manitoba, but rather were those who volunteered. Since the Phase II participants were a subset of participants in Phase I, the same concerns apply regarding digital proficiency and strong views. As Hesse-Biber and Johnson (2015) describe limitations associated with data analysis of "small-*n*" research utilized in Phase II of this study, questions regarding transferability and generalizability are suggested and thereby support the choice of a mixed methods approach. Additionally, there are limitations associated with the interview data that was collected. For instance, a single interview with a researcher they have never met may result in less rich sharing of insights, or the exclusion of useful details. Self-report bias and response bias may have also resulted in inaccurate data from the 11 Phase II participants. Other barriers associated with the essential reliance on, or costs

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

associated with digital communication in remote communities may have limited opportunity for widely representative data collection.

Chapter V: Conclusions

As 63 million teachers worldwide faced extraordinary challenges adapting to school closures and restrictions and 1.57 billion students shifted to remote education in tandem (ICET, 2020, October 8; Meng et al., 2020), Manitoba Grade 9 and 10 science teachers worked to a common goal during the COVID-19 pandemic—to continue to teach science to their students. The development of scientific literacy however, requires practical work with specialized equipment and opportunities to practice the nature of science (Bencze et al., 2020), as “all knowing depends upon the practical...as both foundational and the continuing source of new knowledge” (Layton, 1991, p. 63). Although Manitoba Grades 9 and 10 students had limited opportunity for experiential learning throughout the pandemic, their teachers learned experientially while adapting to the new form of pedagogy required, and the pedagogical decisions they made while teaching under the strain of pandemic lockdowns and restrictions revealed important implications for a scientifically literate citizenry.

Three overarching conclusions resulted from the findings in this study, as follows.

Restrictions to Practical and Collaborative Activities During the COVID-19 Pandemic Seemed to Limit Advancement of Student Scientific Literacy in these Manitoba Science Classrooms

The curricular content and approaches prioritized by Manitoba Grade 9 and 10 science teachers during the COVID-19 pandemic had a comprehensive and multifaceted impact on their potential to advance student scientific literacy. Teacher priorities resulted from the interface of school structure, educational foundations, resources and individual teacher experiences, and reduced their potential to advance student scientific literacy to levels achieved pre-pandemic. While the curricular units and LOs prioritized by Manitoba Grades 9 and 10 science teachers were generally maintained throughout the pandemic, lockdowns and restrictions limited teachers

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

from teaching some LOs requiring practical or collaborative student work. While teachers continued to teach the Grades 9 and 10 science LOs they prioritized through alternative learning activities and instructional approaches, they could not teach some practical or collaborative LOs required for students to develop scientific conceptual understanding, procedural knowledge or scientific attitudes that are critical for the development of functional scientific literacy. It is likely that impacts on the advancement of scientific literacy were different for individual students.

Teachers' Decisions to Prioritize and Teach Certain Units and Learning Outcomes in the Curriculum, Before and During the Pandemic may have Undermined Consistent Development of Student Scientific Literacy in Manitoba Science Classrooms

A certain level of disconnect between the interpretation of the Manitoba Senior Years Grade 9 and 10 curricular documents and its professional implementation to support student scientific literacy appears to exist. The Manitoba Grade 9 science curriculum document, published in 2000 (MET, 2000) and Manitoba Grade 10 science curriculum document, published in 2003 (MEY, 2003) provide the mandated foundational clusters and LOs for each of these final compulsory general science courses. The disruption occurs somewhere between the interpretation of these documents, the curricular priorities and pedagogical decisions made by individual teachers, and the pathway to Grades 9 and 10 student scientific literacy. Where this disruption occurs however, seems to depend upon individual teachers' perception of their curricula and what is most important for Grade 9 and Grade 10 science learners; and during the COVID-19 pandemic, what LOs could effectively be taught through alternatives to practical and collaborative learning amid lockdowns and restrictions.

The findings suggest that individual interpretations of curricular objectives including SLOs, GLOs and Cluster 0 Skills and Attitudes SLOs guide the pedagogical priorities and

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

decisions Manitoba Grades 9 and 10 teachers make, regarding what to teach and how to teach it. Consequently, student development and acquisition of scientific literacy competencies are dependent upon how their science teachers, with diverse backgrounds, interests and expertise, interpret and implement these curricula. Prior to the pandemic, many Grade 9 and 10 teachers did not teach the entirety of their curricula, likely resulting in variable states of functional scientific literacy for students across the province. During the pandemic, as teachers adjusted their teaching amid lockdowns and restrictions to practical work, their inability to teach the entirety of the four clusters and many LOs in these courses through alternative instruction was amplified. Implementation of scientific literacy concepts, skills and attitudes within all clusters in the Grades 9 and 10 science curricula however, is helpful to equip Grades 9 and 10 students for life in the 21st century.

Structural and Instructional Barriers During the Pandemic Limited the Realization of Manitoba Teachers' Perceived Potential to Advance Student Scientific Literacy

The perceived potential of Manitoba Grades 9 and 10 science teachers to effectively advance student scientific literacy during the COVID-19 pandemic may in fact be greater than attained, for several reasons. First, this perceived potential seems to be the cumulative result of varied individual teacher experiences while teaching science during the pandemic, amidst equivalent direction from government and school divisions, and the Manitoba Senior Years Science curriculum documents. On one hand, it was found that teachers felt a certain confidence in their ability to teach science and to foster scientific literacy competencies during the pandemic; but on the other, they were unable to adequately teach the entirety of the Grade 9 or Grade 10 course clusters and many unit SLOs, GLOs and Cluster 0 Overall Skills and Attitudes SLOs that are required for students to develop scientific literacy. Secondly, a perceived level of

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

confidence that alternative learning activities allowed teachers to effectively promote scientific literacy during the pandemic was found. Yet, with restrictions to traditional laboratories and collaborative learning activities, and limited opportunity to teach all four curricular units and many of the LOs, a strong belief that students were unable to effectively learn scientific and technological concepts, skills and attitudes without practical learning opportunities was also found. Although teacher agency permitted the development and implementation of alternative learning activities throughout the pandemic and Grades 9 and 10 teachers continued to teach science to many students who achieved their Grade 9 and/or Grade 10 science credits—their potential to advance scientific literacy was significantly impacted. These impacts were likely experienced in different ways and to varying degrees by different students.

Contributions and Recommendations for Practice, Theory and Research

The findings of this study advance understanding of what Manitoba Grades 9 and 10 science teachers consider most important to foster student conceptual knowledge, procedural skills, and attitudes for the development of functional scientific literacy in the 21st century.

As the development of scientific literacy requires practical work with specialized equipment and opportunities to practice the nature of science, the decisions Manitoba Grades 9 and 10 teachers made while adjusting their teaching to meet pandemic protocols offer significant insights into student development of scientific literacy during this period. Since Verma et al. (2020) indicated “much can be learned about science teaching and learning in relation to our response to COVID-19” (p. 487), the curricular units and learning outcomes teachers prioritized, and did not prioritize during restricted periods of learning are valuable to understanding essential learning outcomes teachers believe are most important to Grades 9 and 10 science learners.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Additionally, significant insights into the relationship science teachers have with the curriculum they teach—how they interpret it, and how they play a significant role in its enactment were gleaned from this study. The findings revealed that Grades 9 and 10 teachers prioritize teaching units and SLOs in three key disciplines: chemistry, biology and physics, both prior to and during the pandemic; and de-emphasized or omitted other units and many Overall Skills and Attitudes SLOs as they developed and tested alternative learning opportunities while aiming to foster scientific literacy without practical, experiential components during the pandemic.

The findings of this study revealed the struggles of these Manitoba Grades 9 and 10 teachers during the COVID-19 pandemic—in teaching, in teaching remotely, and in teaching science during these unprecedented circumstances, and illuminating teachers' decisions regarding what they chose to teach and how they taught it. Science teachers participating in this study had opportunity to reflect on their pedagogical decisions, and on the effectiveness of alternative teaching approaches to advance scientific literacy—whether practical work is restricted or not. As these teachers adjusted their curricular content and utilized alternative teaching approaches in response to restricted practical and collaborative learning opportunities during the pandemic, their perceived effectiveness in supporting student development of scientific literacy was inconsistent and the impacts of adjusted pedagogy were likely more severe for some learners than others. Insights from perceived successful or unsuccessful approaches to the development of scientific literacy were found, in some cases inspiring teacher agency and new pedagogy to foster it.

Several findings extend beyond the scope of this study and while not directly related to the research questions, may be of interest. Such findings include: the pandemic fuelled

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

professional learning for these teachers; the pandemic prompted positive shifts in assessment practices; the pandemic propelled awareness and concern for individual student needs; and that many factors came together during the pandemic to diminish learning. First, the pandemic catalyzed professional development as teachers required new professional knowledge and skills to continue to teach Grades 9 and 10 science to their students. While some were self-reliant and learned new digi-pedagogy skills independently, others worked collaboratively within their school departments to utilize new tools and develop new pedagogies—several of ongoing value for teaching Grades 9 and 10 science. Despite the challenges they experienced responding to the COVID-19 pandemic, these teachers all acknowledged and valued a considerable measure of professional growth. Second, an increased awareness of assessment practices to ensure that assessments better support and more fully reflect learning, was identified among the participant teachers. As teachers adjusted their assessments throughout the pandemic and some utilized digital assessment tools, positive shifts to increased assessment for learning or formative assessment, assessment as learning, and outcome-based assessment were found. Third, during the pandemic, student mental health and well-being became a priority for many of these teachers, above teaching scientific concepts and skills. Moreover, an overall increased awareness of individual student needs during the pandemic was found, considered beneficial to their future practice. Another unanticipated finding was that a combination of factors all came together during the pandemic to diminish student learning in Grades 9 and 10 science: restrictions to practical learning; a lack of suitable resources within the curriculum standards documents; reduced contact time and in-person instruction with students; a temporary change in grading policy; distractions and other matters in students' lives, among others.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

The findings of this study add to the K-12 online, remote and BL science education literature to support science education in circumstances beyond the COVID-19 pandemic; and to the breadth of postpositivist mixed methods case study research—each important to advancing educational scholarship. In further advancing this scholarship, ongoing research to support 21st century scientific literacy in a digital world is paramount. Advancing scientific literacy in Grades 9 and 10 science is of particular interest, as these are the final mandated general science courses in the province; but research investigating scientific literacy development in other grades, and research into the development of supportive, adaptive curricular foundations and teacher resources to aid in future emergent events is also suggested. Ongoing research of science learning impacts resulting from COVID-19 restrictions at all grade levels is important to assessing future student needs and to establish ongoing student' supports. Providing Manitoba science students with the utmost opportunity to become scientifically literate to make informed, critical decisions as “global interdependence; rapid scientific and technological innovation; the need for a sustainable environment, economy and society; and the pervasiveness of science and technology in daily life” (MET, 2000, p. 1.2) reinforce its importance.

Among the recommendations to advance functional scientific literacy for students in Manitoba's Grades 9 and 10 science courses, this study highlights the need for: expanded access to practical and digital learning opportunities; enhanced teacher training and support; and curriculum reorganization and modernization.

For scientific literacy to be attainable in Grades 9 and 10 science courses, students require opportunities to engage in practical learning experiences that focus on the practical applications of science. The development of enhanced technologies and digital resources for alternative pedagogies might support teachers through future events with restricted practical

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

learning opportunities; in other settings where practical learning is simply not feasible such as when students are unable to attend school or school infrastructures do not support laboratories or specialized equipment; and would increase access for science education in remote communities, or for adult education centers and adult learners in distant/remote communities pursuing high school equivalency.

Useful insights from this study into the essential LOs teachers believe are most important for Grade 9 and Grade 10 science learners should inform curriculum and practice. Support from Manitoba Education, along with training opportunities for teachers should be enhanced to promote differentiation and responsive pedagogy in Grades 9 and 10 science, while encouraging implementation of curriculum with equitable opportunity for all Manitoba students to develop functional scientific literacy competencies. These findings show that Manitoba Grades 9 and 10 science teachers with pedagogical expertise in these grades, value practical work as an integral part of learning science, and prioritize LOs they consider essential for learning science and for the development of student scientific literacy in the final mandated science courses. The findings in this study should inform the Manitoba science teaching community of scientific literacy concepts, skills and attitudes teachers deem most important for functional daily living in the 21st century, as well as for student success at the next levels in science.

The findings of this study establish that Manitoba Grades 9 and 10 science teachers require updated science curriculum documents to support student scientific literacy development in the 21st century with modernized descriptive context and current technologies (e.g. data collection via apps), current examples (e.g. microplastics; James Webb Telescope), and current references with accessible digital resources for teaching science. Useful insights into the clusters and LOs Grades 9 and 10 teachers did not prioritize or teach during the COVID-19 pandemic

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

should additionally inform curriculum and science teachers of critical concepts, skills and attitudes that might be emphasized in earlier years, in other grades, or in other courses adopting an interdisciplinary approach—if important for student scientific literacy development, but too extensive for inclusion in Grades 9 and 10 science. A significant priority among Grades 9 and 10 science teachers to focus on teaching content in three of four clusters of each curriculum, versus a focus on student development of scientific literacy was exposed in this study. To counter this, a review of the depth and breadth of topical science content, along with a review and reorganization of the documents to ensure cluster and LO priorities are presented to enhance functional scientific literacy development for all Manitoba students.

References

- Adedoyin, O. B., & Soykan, E. (2020). Covid-19 pandemic and online learning: The challenges and opportunities. *Interactive Learning Environments*, (ahead-of-print), 1–13.
<https://doi.org/10.1080/10494820.2020.1813180>
- Agarkar, S. C. (2019). Influence of learning theories on science education. *Resonance*, 24(8), 847–859. <https://doi.org/10.1007/s12045-019-0848-7>
- Aguirre, J. D., & Selampinar, F. (2020). Teaching chemistry in the time of COVID-19: Memories and the classroom. *Journal of Chemical Education*, 97(9), 2909–2912.
<https://doi.org/10.1021/acs.jchemed.0c00742>
- Akoh, B. (2018). *Determinants of Indigenous student learning with digital technology: A qualitative study in a remote Manitoba First Nations community*. University of Manitoba MSpace. <https://mspace.lib.umanitoba.ca> <https://mspace.lib.umanitoba.ca/items/fed8b939-053d-4673-9584-2ed2bb98c24b>
- Allchin, D. (2014). From science studies to scientific literacy: A view from the classroom. *Science & Education*, 23(9), 1911–1932. <https://doi.org/10.1007/s11191-013-9672-8>
- Almeida, B., Santos, M., & Justi, R. (2022). Aspects and abilities of science literacy in the context of nature of science teaching. *Science & Education*, 31(1), 1–21.
<https://doi.org/10.1007/s11191-022-00324-4>
- Anderson, A. E., Justement, L. B., & Bruns, H. A. (2020). Using real-world examples of the Covid-19 pandemic to increase student confidence in their scientific literacy skills. *Biochemistry and Molecular Biology Education*, 48(6), 678–684.
<https://doi.org/10.1002/bmb.21474>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Anderson, L. B., Mazzone, R., & Lucas, M. A. (2021). Reimagining engagement for (post)pandemic teaching: A multileveled approach. In J. M. Valenzano (Ed.), *Post-pandemic pedagogy: A paradigm shift* (pp. 73-90). Lexington Books.
- Anderson, L. W., Krathwohl, D. R., & Bloom, B. S. (2001). *A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives* (Abridged ed.). Longman.
- Audrain, R. L., Weinberg, A. E., Bennett, A., O'Reilly, J., & Basile, C. G. (2021). Ambitious and sustainable post-pandemic workplace design for teachers: A portrait of the Arizona teacher workforce. In F. M. Reimers (Ed.), *Primary and secondary education during Covid-19: Disruptions to educational opportunity during a pandemic* (pp. 353–381). Springer.
https://doi.org/10.1007/978-3-030-81500-4_14
- Babinčáková, M., & Bernard, P. (2020). Online experimentation during Covid-19 secondary school closures: Teaching methods and student perceptions. *Journal of Chemical Education*, 97(9), 3295–3300. <https://doi.org/10.1021/acs.jchemed.0c00748>
- Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: an approach to medical education*. Springer.
- Bazeley, P. (2018). Integrating analyses in mixed methods research. Sage.
- Bazeley, P., & Brindle, P. (2015). *Mixed methods research*. Sage.
- Beauchamp, D. M., Newton, G., & Monk, J. M. (2021). Adapting literature critique engagement activities for online learning due to Covid-19: Use of online learning groups to promote scientific literacy capabilities in undergraduate nutrition education. *International Journal of Higher Education*, 10(7), 19-33. <https://doi.org/10.5430/ijhe.v10n7p19>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Bencze, L., Pouliot, C., Pedretti, E., Simonneaux, J., & Zeidler, D. (2020). SAQ, SSI and STSE education: defending and extending “science-in-context.” *Cultural Studies of Science Education*, 15(3), 825–851. <https://doi.org/10.1007/s11422-019-09962-7>
- Bhamani, S., Makhdoom, A. Z., Bharuchi, V., Ali, N., Kaleem, S., & Ahmed, D. (2020). Home learning in times of COVID: Experiences of parents. *Journal of Education and Educational Development*, 7(1), 9–26. <https://doi.org/10.22555/joeed.v7i1.3260>
- Bogdan, R.C., & Biklen, S.K. (2007). *Qualitative research for education: An introduction to theory and methods* (5th ed.). Allyn & Bacon.
- Borish, V., Werth, A., Sulaiman, N., Fox, M. F. J., Hoehn, J. R., & Lewandowski, H. J. (2022). Undergraduate student experiences in remote lab courses during the Covid-19 pandemic. *Physical Review. Physics Education Research*, 18(2), 020105–. <https://doi.org/10.1103/PhysRevPhysEducRes.18.020105>
- Britt, M. A., Richter, T., & Rouet, J.-F. (2014). Scientific literacy: The role of goal-directed reading and evaluation in understanding scientific information. *Educational Psychologist*, 49(2), 104–122. <https://doi.org/10.1080/00461520.2014.916217>
- Buck, G., Cook, K., Quigley, C., Eastwood, J., & Lucas, Y. (2009). Profiles of urban, low SES, African American girls' attitudes toward science: A sequential explanatory mixed methods study. *Journal of Mixed Methods Research*, 3(4), 386–410.
- Burgos, D., Tlili, A., & Tabacco, A. (2021). *Radical solutions for education in a crisis context: Covid-19 as an opportunity for global learning*. Springer Singapore. <https://doi.org/10.1007/978-981-15-7869-4>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Byrnes, K., Kiely, P., Dunne, C., McDermott, K., & Coffey, J. C. (2020). Communication, collaboration and contagion: “Virtualisation” of anatomy during Covid-19. *Clinical Anatomy (New York, N.Y.)*, 34(1), 82–89. <https://doi.org/10.1002/ca.23649>
- Calabrese Barton, A., & Tan, E. (2014). “It changed our lives”: Activism, science, greening the club. In L. Bencze, & S. Alsop (Eds.), *Activist science and technology education* (1st ed., pp. 491-508). Springer. <https://doi.org/10.1007/978-94-007-4360-1>.
- Campbell, C., Challen, B., Turner, K., & Stewart, M. (2020). DryLabs20: A new global collaborative network to consider and address the challenges of laboratory teaching with the challenges of Covid-19. *Journal of Chemical Education*, 97(9), 3023–3027. <https://doi.org/10.1021/acs.jchemed.0c00884>
- Carrillo, C., & Flores, M. (2020). Covid-19 and teacher education: a literature review of online teaching and learning practices. *European Journal of Teacher Education*, 43(4), 466–487. <https://doi.org/10.1080/02619768.2020.1821184>
- Chadwick, R., & McLoughlin, E. (2021). Impact of the Covid-19 crisis on learning, teaching and facilitation of practical activities in science upon reopening of Irish schools. *Irish Educational Studies*, 40(2), 197–205. <https://doi.org/10.1080/03323315.2021.1915838>
- Chalmers, C., Carter, M., Cooper, T., & Nason, R. (2017). Implementing “big ideas” to advance the teaching and learning of science, technology, engineering, and mathematics (STEM). *International Journal of Science and Mathematics Education*, 15(Suppl 1), 25–43. <https://doi.org/10.1007/s10763-017-9799-1>
- Chan, B., Baker, J., Bunagan, M., Ekanger, L., Gazley, J., Hunter, R. A., O'Connor, A. R., & Triano, R. (2020). Theory of change to practice: How experimentalist teaching enabled

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- faculty to navigate the Covid-19 disruption. *Journal of Chemical Education*, 97(9), 2788–2792. <https://doi.org/10.1021/acs.jchemed.0c00731>
- Chanapimuk, S., Sawangmek, S., & Nangngam, P. (2018). Using science, technology, society, and environment (STSE) approach to improve the scientific literacy of grade 11 students in plant growth and development. *Journal of Science Learning*, 2(1), 14-20. <https://doi.org/10.17509/jsl.v2i1.11997>
- Chandrasekaran, A. (2020). Transitioning undergraduate research from wet lab to the virtual in the wake of a pandemic. *Biochemistry and Molecular Biology Education*, 48(5), 436–438. <https://doi.org/10.1002/bmb.21386>
- Chen, S. H. (2022). Learning lab skills online: Lessons from implementing video-based instruction for a remote biotechnology lab. *Biochemistry and Molecular Biology Education*. 1-8. <https://doi.org/10.1002/bmb.21667>
- Chen, T., Peng, L., Jing, B., Wu, C., Yang, J., & Cong, G. (2020). The impact of the Covid-19 pandemic on user experience with online education platforms in China. *Sustainability (Basel, Switzerland)*, 12(18), 7329–. <https://doi.org/10.3390/SU12187329>
- Cheng, X., Chan, L. K., Pan, S., Cai, H., Li, Y., & Yang, X. (2021). Gross anatomy education in China during the Covid-19 pandemic: A national survey. *Anatomical Sciences Education*, 14(1), 8–18. <https://doi.org/10.1002/ase.2036>
- Chickering, A.W. & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin*, 39(7), 3–7.
- Chiu, M. (2013). Bridging the gaps between policy and practice on equity for science education reforms. In J. Bianchini, V. Akerson, A. Calabrese Barton, O. Lee, & R. Rodriguez (Eds.),

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Moving the equity agenda forward: Equity research, practice, and policy in science education (pp. 53-64). Springer.

Cohen Zilka, G. (2021). Distance learning during the Covid-19 crisis as perceived by preservice teachers. *Issues in Informing Science & Information Technology Education*, 18, 141–159.
<https://doi.org/10.28945/4795>

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). Sage. <https://doi.org/10.4135/9781452230153.n4>

Crato, N., & Patrinos, H. A. (2025). *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed.). Springer.
<https://doi.org/10.1007/978-3-031-69284-0>

Creamer, E. G. (2018). An introduction to fully integrated mixed methods research. Sage.

Creamer, E. G. (2018). Striving for methodological integrity in mixed methods research: The difference between mixed methods and mixed-up methods. *Journal of Engineering Education* (Washington, D.C.), 107(4), 526–530. <https://doi.org/10.1002/jee.20240>

Creswell, J. W. & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage.

Creswell, J. W., & Poth, C. N. (2018). Qualitative inquiry and research design: Choosing among five approaches (4th ed.). Sage.

Croce, K., & Firestone, J. (2020). *Developing science literacy in the 21st century*. Information Age Publishing.

Crujeiras-Pérez, B., & Jiménez-Aleixandre, M. P. (2017). High school students' engagement in planning investigations: Findings from a longitudinal study in Spain. *Chemistry Education Research and Practice*, 18(1), 99–112. <https://doi.org/10.1039/c6rp00185h>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Cutri, R., Whiting, E., & Bybee, B. (2019). Knowledge production and power in an online critical multicultural teacher education course. *Educational Studies*, 56(1), 54–65.

<https://doi.org/10.1080/00131946.2019.1645016>.

Dale, E. (1970). A truncated section of the cone of experience. *Theory into Practice* 9(2), 96–100. <https://doi.org/10.1080/00405847009542260>.

Daniela, L., & Visvizi, A. (2022). Remote learning in times of pandemic: Issues, implications and best practice. Routledge.

Daniels, H. (1993). *Charting the agenda: Educational activity after Vygotsky* (1st ed.).

Routledge. <https://doi.org/10.4324/9780203133019>

Darling-Hammond, H., & Hyler, M. (2020). Preparing educators for the time of Covid ... and beyond. *European Journal of Teacher Education*, 43(4), 457–465.

<https://doi.org/10.1080/02619768.2020.1816961>

Davies, A. (2020). *Making classroom assessment work* (4th ed.). Hignell Book Printing.

Denzin, N. K., & Lincoln, Y. S. (2008). *Collecting and interpreting qualitative materials* (3rd ed.). Sage.

Dong, C., Cao, S., & Li, H. (2020). Young children's online learning during Covid-19 pandemic: Chinese parents' beliefs and attitudes. *Children and Youth Services Review*, 118, 105440–

105440. <https://doi.org/10.1016/j.childyouth.2020.105440>

Donovan, W. (2020). The whiplash of a Covid-19 teaching pivot and the lessons learned for the future. *Journal of Chemical Education*, 97(9), 2917–2921.

<https://doi.org/10.1021/acs.jchemed.0c00755>

Doyle, L., Brady, A. M., Byrne, G., Baklien, B., Asano, M., Finlayson, M., Radil, A. I., Zhang, X., Hanson, W. E., Martin-Khan, M., Wade, V., Sankaran, S., Scales, J., Howden-Chapman,

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- P., Lichtenstein, G., Higgs, M., Gunaydin, S., Gilbertson, J., Mary Tod, A., ... Lusambili, A. (2019). *SAGE mixed methods research*. Sage.
- Driessen, B., Beatty, A., Stokes, A., Wood, S., & Ballen, C. (2020). Learning principles of evolution during a crisis: An exploratory analysis of student barriers one week and one month into the Covid-19 pandemic. *Ecology and Evolution*, 10(22), 12431–12436.
<https://doi.org/10.1002/ece3.6741>
- Dube, B. (2020). Rural online learning in the context of Covid 19 in South Africa: Evoking an inclusive education approach. *Multidisciplinary Journal of Educational Research*, 10(2), 135–157. <https://doi.org/10.17583/remie.2020.5607>
- Dukes III, A. D. (2020). Teaching an instrumental analysis laboratory course without instruments during the Covid-19 pandemic. *Journal of Chemical Education*, 97(9), 2967–2970.
<https://doi.org/10.1021/acs.jchemed.0c00648>
- Duran, M., Höft, M., Medjahed, B., Lawson, D. B., & Orady, E.A. (2016). STEM learning: IT integration and collaborative strategies. Springer. <https://doi.org/10.1007/978-3-319-26179-9>
- Eisenhart, M. (2009). Generalization from qualitative inquiry. In K. Ercikan, & W. M. Roth (Eds.), *Generalizing from educational research: Beyond qualitative and quantitative polarization* (pp. 51 – 66). Routledge. <https://doi.org/10.4324/9780203885376>
- Enns, L. (2021, January). Mental health drops again. *The Manitoba Teacher*, 16.
- Erduran, M., Mugaloglu, E., & Irzik, G. (2012). Interactions of economics of science and science education: Investigating the implications for science teaching and learning. *Science & Education*, 22(10), 2405–2425. <https://doi.org/10.1007/s11191-012-9519-8>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Evans, D. J., Bay, B. H., Wilson, T. D., Smith, C. F., Lachman, N., & Pawlina, W. (2020). Going virtual to support anatomy education: A STOPGAP in the midst of the Covid-19 pandemic. *Anatomical Sciences Education*, 13(3), 279–283. <https://doi.org/10.1002/ase.1963>
- Feinstein, N. (2011). Salvaging science literacy. *Science Education (Salem, Mass.)*, 95(1), 168–185. <https://doi.org/10.1002/sce.20414>
- Fendler, L. (2006). Why generalizability is not generalizable. In P. Smeyers, & M. Depaepe (Eds.), *Educational Research: Why 'What Works' Doesn't Work* (pp. 51-64). Springer, Dordrecht. https://doi-org.uml.idm.oclc.org/10.1007/978-1-4020-5308-5_3
- Fenwick, T. (2001). Tides of change: New themes and questions in workplace learning. *New Directions for Adult and Continuing Education*, 2001(92), 3–18. <https://doi.org/10.1002/ace.36>
- Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs-principles and practices. *Health Services Research*, 48(6pt2), 2134–2156. <https://doi.org/10.1111/1475-6773.12117>
- Gajderowicz, T., & Jakubowski, M. (2025). Oland: Education during and after Covid-19 pandemic and educational reforms. In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 121-134). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Garcia-Vedrenne, O., Orland, C., Ballare, K. M., Shapiro, B., & Wayne, R. (2020). Ten strategies for a successful transition to remote learning: Lessons learned with a flipped course. *Ecology and Evolution*, 10(22), 12620–34. <https://doi.org/10.1002/ece3.6760>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Gillis, K., & Krull, L.M. (2020). Covid-19 remote learning transition in spring 2020: Class structures, student perceptions, and inequality in college courses. *Teaching Sociology*, 48(4), 283–299. <https://doi.org/10.1177/0092055X20954263>
- Gicheva, D. (2022). Teachers' working hours during the Covid-19 Pandemic. *Educational Researcher*, 51(1), Article 0013189. <https://doi.org/10.3102/0013189X211056897>
- Giordano, A.N., & Christopher, C. R. (2020). Repurposing best teaching practices for remote learning environments: Chemistry in the news and oral examinations during Covid-19. *Journal of Chemical Education*, 97(9), 2815–2818. <https://doi.org/10.1021/acs.jchemed.0c00753>
- Gonçalves, E., & Capucha, L. (2020). Student-centered and ICT-enabled learning models in veterinarian programs: What changed with Covid-19? *Education Sciences*, 10(11), 1–17. <https://doi.org/10.3390/educsci10110343>
- Graham, C. R., Borup, J., Pulham, E., & Larsen, R. (2019). K-12 blended teaching readiness: Model and instrument development. *Journal of Research on Technology in Education*, 51(3), 239–258. <https://doi.org/10.1080/15391523.2019.1586601>
- Greene, J. C. (2007). *Mixed methods in social inquiry* (1st ed.). Jossey-Bass.
- Gresch, H., & Bögeholz, S (2013). Identifying non-sustainable courses of action: A prerequisite for decision-making in education for sustainable development. *Research in Science Education (Australasian Science Education Research Association)*, 43(2), 733–754. <https://doi.org/10.1007/s11165-012-9287-0>
- Gya, R., & Bjune, A. E. (2021). Taking practical learning in STEM education home: Examples from do-it-yourself experiments in plant biology. *Ecology and Evolution*, 11(8), 3481–3487. <https://doi.org/10.1002/ece3.7207>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Hancock, F., Friedrichsen, P.J., Kinslow, A.T., & Sadler, T.D. (2019). Selecting socio-scientific issues for teaching: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science & Education*, 28(6), 639–667. <https://doi.org/10.1007/s11191-019-00065-x>
- Hanushek, E. A., & Strauss, B. (2025). United States: The size and variation of the pandemic learning losses. In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 189-203). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Harrell, J., & Wendt, K. (2019). The impact of blended learning on community of inquiry and perceived learning among high school learners enrolled in a public charter school. *Journal of Research on Technology in Education*, 51(3), 259–272. <https://doi.org/10.1080/15391523.2019.1590167>
- Harrison, N. & McCaig, C. (2017). Examining the epistemology of impact and success of educational interventions using a reflective case study of university bursaries. *British Educational Research Journal*, 43(2), 290–309. <https://doi.org/10.1002/berj.3263>
- He, L., Yang, N., Xu, L., Ping, F., Li, W., Sun, Q., Li, Y., Zhu, H., & Zhang, H. (2021). Synchronous distance education vs traditional education for health science students: A systematic review and meta-analysis. *Medical Education*, 55(3), 293–308. <https://doi.org/10.1111/medu.14364>
- Heng, Z. S., Koh, D. W., Yeo, J. Y., Ooi, C., & Gan, S. K. (2022). Effects of different delivery modes on teaching biomedical science practical skills in higher education during the 2021 pandemic measures. *Biochemistry and Molecular Biology Education*, 50(4), 403–413. <https://doi.org/10.1002/bmb.21637>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Herrera-Pavo, M. Á., Jaramillo-Baquerizo, C., Valencia, V. H. (2025). Ecuador: Inserting the country into the PISA experience. In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 37-50). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Hesse-Biber, S., & Johnson, R. B. (2015). *The Oxford handbook of multimethod and mixed methods research inquiry*. Oxford University Press.
- Hodson, D. (1993). Re-thinking old ways: Towards A more critical approach to practical work in school science. *Studies in Science Education*, 22(1), 85–142.
<https://doi.org/10.1080/03057269308560022>
- Hodson, D. (2014). Learning Science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, 36(15), 2534–2553. <https://doi.org/10.1007/s11191-011-9368-x>
- Hoffman, J., & Miller E. (2020). Addressing the consequences of school closure due to Covid-19 on children's physical and mental well-being. *World Medical and Health Policy*, 12(3), 300–310. <https://doi.org/10.1002/wmh3.365>
- Hong, H. Y., Lin, P. Y., Chen, B., & Chen, N. (2018). Integrated STEM learning in an idea-centered knowledge-building environment. *Asia-Pacific Education Researcher*, 2018, 1-14.
<https://doi.org/10.1007/s40299-018-0409-y>
- Hothi, N., Bharadwaj, N., Chowdhury, S., Ahluwalia, D., Srivastav, A. L., Dutt, I., Sharma, S. R., Kumar, A., Taneja, A., Gupta, M., Kumra, N., Batra, S. (2022). An investigative study of students' perspective towards transition to online teaching during Covid-19 pandemic. *AIP Conference Proceedings*, 2451(1). <https://doi.org/10.1063/5.0095202>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Howitz, W. J., Thane, T. A., Frey, T. L., Wang, X. S., Gonzales, J. C., Tretbar, C. A., Seith, D. D., Saluga, S. J., Lam, S., Nguyen, M. M., Tieu, P., Link, R. D., & Edwards, K. D. (2020). Online in no time: Design and implementation of a remote learning first quarter general chemistry laboratory and second quarter organic chemistry laboratory. *Journal of Chemical Education*, 97(9), 2624–2634. <https://doi.org/10.1021/acs.jchemed.0c00895>
- Hoy, W. K. (2010). *Quantitative research in education: A primer*. Sage.
- Hughes, S., & Lewis, H. (2020). Tensions in current curriculum reform and the development of teachers' professional autonomy. *The Curriculum Journal*, 31(2), 290–302. <https://doi.org/10.1002/curj.25>
- Huillery, E. (2025). France: How Covid-19 pandemic affected learning and equity of the education system. In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 79-92). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Humphrey, E. A., & Wiles, J. R. (2021). Lessons learned through listening to biology students during a transition to online learning in the wake of the Covid-19 pandemic. *Ecology and Evolution*, 11(8), 3450–3458. <https://doi.org/10.1002/ece3.7303>
- Hunter, K., Hari, S., Egbu, C., & Kelly, J. (2005). Grounded theory: Its diversification and application through two examples from research studies on knowledge and value management. *Electronic Journal of Business Research Methods*, 3(1), 57–68.
- Hwang, W., & Hariyanti, U. (2020). Investigation of students' and parents' perceptions of authentic contextual learning at home and their mutual influence on technological and pedagogical aspects of learning under Covid-19. *Sustainability*, 12(10074), 10074–. <https://doi.org/10.3390/su122310074>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

International Conference on Education and Technology (ICET). (2020, October 8). [Conference].

Technology-based education for the next generation. Retrieved from

<http://icet.fip.um.ac.id/index.php/2020-6th-icet/>

International Council for Education and Teaching (ICET). (2020). Teacher experiences and practices during Covid-19: Interim report of teachers.

<https://drive.google.com/drive/folders/1Qq5GuhNw3J56tcT4SzkcUFHMQt3Gk0ro?usp=sharing>

Itin, C. (1999). Reasserting the philosophy of experiential education as a vehicle for change in the 21st century. *Journal of Experiential Education*, 22, 91-98.

<https://doi.org/10.1177/105382599902200206>

Iwabuchi, K., Hodama, K., Onishi, Y., Miyazaki, S., Nakae, S., & Suzuki, K. H. (2021). Covid-19 and education on the front lines in Japan: What caused learning disparities and how did the government and schools take initiative? In F. M. Reimers (Ed.), *Primary and secondary education during Covid-19: Disruptions to educational opportunity during a pandemic* (pp. 125–151). Springer. https://doi.org/10.1007/978-3-030-81500-4_5

Jack, B., Yin, H., & Yore, L. (2014). The synergistic effect of affective factors on student learning outcomes. *Journal of Research in Science Teaching*, 51(8), 1084–1101.

<https://doi.org/10.1002/tea.21153>

Jackson, E. (2013). Choosing a methodology: Philosophical underpinning. *Practitioner Research in Higher Education Journal*, 7(1). <http://194.81.189.19/ojs/index.php/prhe>

Johnson, M., Macalalag, A.Z., & Dunphy, J. (2020). Incorporating socioscientific issues into a STEM education course: Exploring teacher use of argumentation in SSI and plans for

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- classroom implementation. *Disciplinary and Interdisciplinary Science Education Research*, 2(1), 1–12. <https://doi.org/10.1186/s43031-020-00026-3>
- Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, 1(2), 112–133. <https://doi.org/10.1177/1558689806298224>
- Jose, S., Patrick, P. G., & Moseley, C. (2017). Experiential learning theory: The importance of outdoor classrooms in environmental education. *International Journal of Science Education, Part B*, 7(3), 269–284. <https://doi.org/10.1080/21548455.2016.1272144>.
- Juuti, K., Lavonen, J., Salonen, V., Salmela-Aro, K., Schneider, B., & Krajcik, J. (2021). A teacher-researcher partnership for professional learning: Co-designing project-based learning units to increase student engagement in science classes. *Journal of Science Teacher Education*, 32(6), 625–641. <https://doi.org/10.1080/1046560X.2021.1872207>
- Kaup, J., Jain, R., Shivalli, S., Pandey, S., & Kaup, S. (2020). Sustaining academics during Covid-19 pandemic: The role of online teaching-learning. *Indian Journal of Ophthalmology*, 68(6), 1220–1221. https://doi.org/10.4103/ijo.IJO_1241_20
- Kelley, E. W. (2020). Reflections on three different high school chemistry lab formats during Covid-19 remote learning. *Journal of Chemical Education*, 97(9), 2606–2616. <https://doi.org/10.1021/acs.jchemed.0c00814>
- Kim, K., Ko, Y., & Lee, H. (2019). The effects of community-based socioscientific issues program (SSI-COMM) on promoting students' sense of place and character as citizens. *International Journal of Science and Mathematics Education*, 18(3), 399–418. <https://doi.org/10.1007/s10763-019-09976-1>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Kim, L., & Asbury, L. (2020). "Like a rug had been pulled from under you": The impact of Covid-19 on teachers in England during the first six weeks of the UK lockdown. *British Journal of Educational Psychology*, 90(4), 1062–1083. <https://doi.org/10.1111/bjep.12381>
- Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, 6(5), 26-41. <https://doi.org/10.5430/ijhe.v6n5p26>
- Kochhar, S., Tasnim, T., & Gupta, A. (2022). Is cadaveric dissection essential in medical education? A qualitative survey comparing pre-and post-Covid-19 anatomy courses. *Journal of Osteopathic Medicine*. 1-8. <https://doi.org/10.1515/jom-2022-0016>
- Kolb, A. Y., & Kolb, D. A. (2012). Experiential learning theory. *Encyclopedia of the Sciences of Learning*, 149-153. https://doi.org/10.1007/978-1-4419-1428-6_227
- Koohang, A., Paliszkievicz, J., Goluchowski, J., & Nord, J. H. (2016). Active learning for knowledge construction in e-learning: A replication study. *The Journal of Computer Information Systems*, 56(3), 238-243. <https://doi.org/10.1080/08874417.2016.1153914>
- Kosaretsky, S., Zair-Bek, S., Kersha, Y., & Zvyagintsev, R. (2021). General education in Russia during Covid-19: Readiness, policy response, and lessons learned. In F. M. Reimers (Ed.), *Primary and secondary education during Covid-19: Disruptions to educational opportunity during a pandemic* (pp. 227–261). Springer. https://doi.org/10.1007/978-3-030-81500-4_9
- Kuhfeld, M., Soland, J., & Lewis, K. (2022). Test score patterns across three Covid-19-impacted school years. *Educational Researcher*, 51(7), 500–506. <https://doi.org/10.3102/0013189X221109178>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Kuk, H., & Holst, J. D. (2018). A dissection of experiential learning theory: alternative approaches to reflection. *Adult Learning*, 29(4), 150-157.
<https://doi.org/10.1177/1045159518779138>
- Kumi-Yeboah, A., Dogbey, J., & Yuan, K. (2018). Exploring factors that promote online learning experiences and academic self-concept of minority high school students. *Journal of Research on Technology in Education*, 50(1), 1–17. <https://doi.org/10.1080/15391523.2017.1365669>
- Kvale, S., & Brinkmann, S. (2015). *InterViews: Learning the craft of qualitative research interviewing* (3rd Ed.). Sage.
- Kyne, S., & Thompson, C. (2020). The Covid cohort: Student transition to university in the face of a global pandemic. *Journal of Chemical Education*, 97(9), 3381–3385.
<https://doi.org/10.1021/acs.jchemed.0c00769>
- Labov, J., Olson, S. (2014). *STEM learning is everywhere: summary of a convocation on building learning systems* (1st ed.). National Academies Press. <https://doi.org/10.17226/18818>
- Layton, D. (1991). Science education and praxis: The relationship of school science to practical action. *Studies in Science Education*, 19(1), 43–79.
<https://doi.org/10.1080/03057269108559992>
- Lavonen, J., & Salmela-Aro, K. (2021). Experiences of moving quickly to distance teaching and learning at all levels of education in Finland. In F. M. Reimers (Ed.), *Primary and secondary education during Covid-19: Disruptions to educational opportunity during a pandemic* (pp. 105–123). Springer. https://doi.org/10.1007/978-3-030-81500-4_4
- Lederman, N. G., & Abell, S. K. (2014). *Handbook of research on science education* (Vol. 2).
<https://doi.org/10.4324/9780203097267>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education*, 23(2), 285–302. <https://doi.org/10.1007/s11191-012-9503-3>
- Leung, J. S. C., Wong, K. L., & Chan, K. K. H. (2020). Pre-service secondary science teachers' beliefs about teaching socio-scientific issues. In J. Dillon, J. A. Neilsen, & M. Evagorou (Eds.), *Science Teacher Education for Responsible Citizenship* (Vol. 52, pp. 21–39). Springer. https://doi.org/10.1007/978-3-030-40229-7_3
- Lin, C., Chai, C. S., & Jong, M. S. (2019). A PISA-2015 comparative meta-analysis between Singapore and Finland: Relations of students' interest in science, perceived ICT competence, and environmental awareness and optimism. *International Journal of Environmental Research and Public Health*, 16(24), 5157–5171. <https://doi.org/10.3390/ijerph16245157>
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.
- Lingard, L. (2019). Beyond the default colon: Effective use of quotes in qualitative research. *Perspectives on Medical Education*, 8(6), 360–364. <https://doi.org/10.1007/s40037-019-00550-7>
- Liu, S. (2016). Teaching environmental issues in science classroom: Status, opportunities, and strategies. In M. Chiu (Ed.), *Science education research and practices in Taiwan challenges and opportunities* (1st ed., pp. 371–386). Springer. <https://doi.org/10.1007/978-981-287-472-6>
- Longhurst, G. J., Stone, D. M., Duloher, K., Scully, D., Campbell, T., & Smith, C. F. (2020). Strength, weakness, opportunity, threat (SWOT) analysis of the adaptations to anatomical education in the United Kingdom and Republic of Ireland in response to the Covid-19 pandemic. *Anatomical Sciences Education*, 13(3), 301–311. <https://doi.org/10.1002/ase.1967>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Loughran, J. (2011). Responding to the challenge of scientific literacy: A whole school approach to scientific literacy. In J. Loughran, K. Smith, & A. Berry (Eds.), *Scientific literacy under the microscope: A whole school approach to science teaching and learning*. (pp. 139-148). Springer. <https://doi.org/10.1007/978-94-6091-528-4>
- Low, E. Z., O'Sullivan, N. J., Sharma, V., Sebastian, I., Meagher, R., Alomairi, D., Alhouti, E. H., Donohoe, C. L., & Kelly, M. E. (2022). Assessing medical students' perception and educational experience during Covid-19 pandemic. *Irish Journal of Medical Science*. 1971-. <https://doi.org/10.1007/s11845-022-03118-3>
- MacIntosh, M. (2021, January 16). Remote learning not such a cold, distant affair. *The Winnipeg Free Press*. <https://www.winnipegfreepress.com>
- MacLean, C. (2020, August 20). Demonstration at legislature points to pandemic risk of close quarters in Manitoba classrooms. *CBC News*. <https://www.cbc.ca/news/canada/manitoba/class-size-demonstration-manitoba-legislature-1.5694309>
- Maia, P., Justi, R., & Santos, M. (2021). Aspects about science in the context of production and communication of knowledge of Covid-19. *Science & Education*, 30(5), 1075-1098. <https://doi.org/10.1007/s11191-021-00229-8>
- Manitoba Education. (2020). *Enrolment report September 30, 2020*. https://www.edu.gov.mb.ca/k12/finance/sch_enrol/
- Manitoba Education. (2021). *K-12 science curriculum updates*. <https://www.edu.gov.mb.ca/k12/cur/science/updates.html>
- Manitoba Education, Citizenship and Youth. (2006). *Grade 11 chemistry. A foundation for implementation*. https://www.edu.gov.mb.ca/k12/cur/science/found/gr11_chem/full_doc.pdf

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Manitoba Education and Early Childhood Learning. (2022). *My learning at home*.

<https://www.edu.gov.mb.ca/k12/mylearning/index.html>

Manitoba Education and Training. (2000). Senior 1 science: A foundation for implementation.

https://www.edu.gov.mb.ca/k12/cur/science/found/s1/full_doc.pdf

Manitoba Education and Youth. (2003). Senior 2 science: A foundation for implementation.

https://www.edu.gov.mb.ca/k12/cur/science/found/s2/s2_fulldoc.pdf

Manitoba News Releases. (2020, March 31). Manitoba suspends classroom learning indefinitely amid Covid-19 pandemic.

<https://news.gov.mb.ca/news/index.html?item=47341&posted=2020-03-31>

Manitoba News Releases. (2020, June 30). Manitoba government releases feedback on phase three of Covid-19 reopening, school start plans.

<https://news.gov.mb.ca/news/index.html?item=48546>

Manitoba Teachers' Society (2021). Speak out on Bill 45. *The Manitoba Teacher*, January/February, 20.

Marshall, D. T. (2022). Covid-19 and the classroom: How schools navigated the great disruption. Lexington Books.

Mat Roni, S., Merga, M. K., & Morris, J. E. (2020). *Conducting quantitative research in education* (1st ed.). Springer. <https://doi.org/10.1007/978-981-13-9132-3>

Maxwell, J. A. (2022). Integration in mixed methods research: An alternative perspective. In J. H. Hitchcock & A. J. Onwuegbuzie (Eds.), *The Routledge handbook for advancing integration in mixed methods research* (1st ed., pp. 86–93). Routledge.

<https://doi.org/10.4324/9780429432828-8>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- McBride, J. W., Bhatti, M. I., Hannan, M. A., & Feinberg, M. (2004). Using an inquiry approach to teach science to secondary school science teachers. *Physics Education*, 39(5), 434–439. <https://doi.org/10.1088/0031-9120/39/5/007>
- McGuire, S. Y., & McGuire, S. (2018). Teach yourself how to learn: Strategies you can use to ace any course at any level (1st ed.). Stylus Publishing.
- McKim, C. A. (2017). The value of mixed methods research: A mixed methods study. *Journal of Mixed Methods Research*, 11(2), 202–222. <https://doi.org/10.1177/1558689815607096>
- McKnight, K., Hope, S., Marss, S., & Pitre-Martin, M. (2022). Lessons learned from an urban teacher residency. In Marshall, D. T. (Ed.), *Covid-19 and the classroom: How schools navigated the great disruption* (pp. 247–281). Lexington Books.
- Meng, S., Song, X., Li, Y., Tan, Z., Yan, Y., & Zhang, X. (2020). High-quality inorganic chemistry teaching during Covid-19. *Journal of Chemical Education*, 97(9), 2945–2949. <https://doi.org/10.1021/acs.jchemed.0c00874>
- Merriam, S. B. (1998). Qualitative research and case study applications in education (2nd ed.) Jossey-Bass.
- Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). Jossey-Bass.
- Miles, M. B., & Huberman, A. M. (2002). *The qualitative researcher's companion*. Sage.
- Moon, J. A. (2004). *A handbook of reflective and experiential learning: Theory and practice* (1st ed.). Routledge. <https://doi.org/10.4324/9780203416150>
- Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education*, 101(6), 1034–1060.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Morse, J. M., Bowers, B. J., Charmaz, K., Clark, A. E., Cobin, J., Porr, C. J., Noerager Stern, P.

E. (Eds.). (2021). *Developing grounded theory: The second generation revisited* (2nd ed.).

Routledge.

Morse, M. and Field, A. (1995) *Qualitative research methods for health professionals*. Sage.

Moura, C. B. (2025). *A sociopolitical turn in science education: Towards post-pandemic worlds*

(C. B. Moura, Ed.; 1st ed., Vol. 62). Springer. <https://doi.org/10.1007/978-3-031-78586-3>

Mueller, M., & Zeidler, D. (2010). Moral-ethical character and science education: Ecojustice

ethics through socioscientific issues (SSI). In D. Tippins, M. Mueller, M. van Eijck, & J.

Adams (Eds.), *Cultural studies and environmentalism. The confluence of ecoJustice, place-based (science) education, and Indigenous knowledge systems* (1st ed., Vol. 3, pp. 105-128).

Springer. <https://doi.org/10.1007/978-90-481-3929-3>

Murray, J.J. (2014). The logic of consensus on the foundations of science education in Canada: A

Delphi study. University of Manitoba MSpace. <https://mspace.lib.umanitoba.ca>

Mutambuki, J. M., Mwavita, M., Muteti, C. Z., Jacob, B. I., & Mohanty, S. (2020).

Metacognition and active learning combination reveals better performance on cognitively demanding general chemistry concepts than active learning alone. *Journal of Chemical Education*, 97(7), 1832–1840. <https://doi.org/10.1021/acs.jchemed.0c00254>

Natale, C. C., Mello, P. S., Trivelato, S. L. F., Marzin-Janvier, P., & Manzoni-De-Almeida, D.

(2021). Evidence of scientific literacy through hybrid and online biology inquiry-based learning activities. *Higher Learning Research Communications*, 11, 33–49.

<https://doi.org/10.18870/HLRC.V11I0.1199>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Newman, K., & Stock, N. L. (2022). Remote teaching of a graduate-level instrument repair and maintenance course using take-home kits and laboratory demonstrations. *Journal of Chemical Education*, 99(7), 2507–2511. <https://doi.org/10.1021/acs.jchemed.1c01083>
- Nida, R., Rahayu, S., & Eilks, I. (2020). A survey of Indonesian science teachers' experience and perceptions toward socio-scientific issues-based science education. *Education Sciences*, 10(2), 39-53. <https://doi.org/10.3390/educsci10020039>
- Noel, T. C., Rubin, J. E., Acebo Guerrero, Y., Davis, M. C., Dietz, H., Libertucci, J., & Sukdeo, N. (2020). Keeping the microbiology lab alive: Essential microbiology lab skill development in the wake of Covid-19. *Canadian Journal of Microbiology*, 66(10), 603–604. <https://doi.org/10.1139/cjm-2020-0373>
- Oates, T. (2025). England: Turbulent years—PISA 2022 and Covid-19 school disruption. In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 51-64). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Opere, W. M. (2021). Negative impacts of the current Covid-19 crisis on science education in Kenya: How certain can we be about the efficacy of the science learning framework online? *Journal of Microbiology & Biology Education*, 22(2), 1-6. <https://doi.org/10.1128/JMBE.V22I1.2559>
- Osborne, J., & Pimentel, D. (2022). Science, misinformation, and the role of education. *Science*, 378(6617), 246–248. <https://doi.org/10.1126/science.abq8093>
- Ożadowicz, A. (2020). Modified blended learning in engineering higher education during the Covid-19 lockdown-building automation courses case study. *Education Sciences*, 10(10), 292-311. <https://doi.org/10.3390/educsci10100292>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Pather, N., Blyth, P., Chapman, J. A., Dayal, M. R., Flack, N. A. M., Fogg, Q. A., Green, R. A., Hulme, A. K., Johnson, I. P., Meyer, A. J., Morley, J. W., Shortland, P. J., Štrkalj, G., Štrkalj, M., Valter, K., Webb, A. L., Woodley, S. J., & Lazarus, M. D. (2020). Forced disruption of anatomy education in Australia and New Zealand: An acute response to the Covid-19 pandemic. *Anatomical Sciences Education*, 13(3), 284–300. <https://doi.org/10.1002/ase.1968>
- Patra, A., Chaudhary, P., & Ravi, K. S. (2021). Adverse impact of Covid-19 on anatomical sciences teachers of India and proposed ways to handle this predicament. *Anatomical Sciences Education*, 14(2), 163-165. <https://doi.org/10.1002/ase.2052>
- Pedretti, E., & Nazir, J. (2011). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education*, 95, 601-626. <https://doi.org/10.1002/sce.20435>
- Petersen, K., & Kolb, D. (2018). Expanding awareness and contact through experiential learning. *Gestalt Review*, 22(2), 226-248. <https://doi.org/10.5325/gestaltreview.22.2.0226>
- Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and educational research*. Rowman & Littlefield.
- Plano Clark, V. L., & Ivankova, N. V. (2016). *Mixed methods research: A guide to the field*. (1st ed., Vol. 3). Sage. <https://doi.org/10.4135/9781483398341>
- Pregowska, A., Masztalerz, K., Garlińska, M., & Osial, M. (2021). A worldwide journey through distance education—from the post office to virtual, augmented and mixed realities, and education during the Covid-19 pandemic. *Education Sciences*, 11(3), 118-144. <https://doi.org/10.3390/educsci11030118>
- Price, J. F., & McNeill, K. L. (2013). Toward a lived science curriculum in intersecting figured worlds: An exploration of individual meanings in science education. *Journal of Research in Science Teaching*, 50(5), 501–529. <https://doi.org/10.1002/tea.21084>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231. <https://doi.org/10.1002/j.2168-9830.2004.tb00809.x>

Puntambekar, S., Gnesdilow, D., Dornfeld Tissenbaum, C., Narayanan, N., & Rebello, N. (2020). Supporting middle school students' science talk: A comparison of physical and virtual labs. *Journal of Research in Science Teaching*, 58(3), 392-419. <https://doi.org/10.1002/tea.21664>

Qiang, Z., Obando, A. G., Chen, Y., & Ye, C. (2020). Revisiting distance learning resources for undergraduate research and lab activities during Covid-19 pandemic. *Journal of Chemical Education*, 97(9), 3446–3449. <https://doi.org/10.1021/acs.jchemed.0c00609>

Rahayu, S. (2019). Socio-scientific issues (SSI) in chemistry education: Enhancing both students' chemical literacy & transferable skills. *Journal of Physics: Conference Series*, 1227(1), 1-8. <https://doi.org/10.1088/1742-6596/1227/1/012008>

Reeves, S.M., Crippen, K. J., & McCray, E. D. (2021). The varied experience of undergraduate students learning chemistry in virtual reality laboratories. *Computers and Education*, 175, 104320–. <https://doi.org/10.1016/j.compedu.2021.104320>

Regan, J.-A. (2012). The role obligations of students and lecturers in higher education. *Journal of Philosophy Education*, 46(1), 14-24. <https://doi.org/10.1111/j.1467-9752.2011.00834.x>

Reicher, D. (2020). Debate: Remote learning during Covid-19 for children with high functioning autism spectrum disorder. *Child and Adolescent Mental Health*, 25(4), 263–264. <https://doi.org/10.1111/camh.12425>

Reimers, F., & Schleicher, A. (2020). Schooling disrupted, schooling rethought: How the Covid 19 pandemic is changing education. OECD. <https://www.oecd.org/en/publications/schooling->

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

disrupted-schooling-rethought-how-the-covid-19-pandemic-is-changing-education_68b11faf-en.html

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science teaching* (pp. 729–780). Routledge.

Robertson, L. (2018). Toward an epistemology of active learning in higher education and its promise. In M. D. Lytras, A. Misseyanni, P. Papadopouou, & C. Marouli (Eds.), *Active learning strategies in higher education: Teaching for leadership, innovation, and creativity* (pp. 17-44). Emerald Publishing. <https://doi.org/10.1108/978-1-78714-487-320181002>

Rossettini, G., Geri, T., Turolla, A., Viceconti, A., Scumà, C., Mirandola, M., Dell'Isola, A., Gianola, S., Maselli, F., & Palese, A. (2021). Online teaching in physiotherapy education during Covid-19 pandemic in Italy: a retrospective case-control study on students' satisfaction and performance. *BMC Medical Education*, 21(1), 456–456. <https://doi.org/10.1186/s12909-021-02896-1>

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education*, 36(1), 1–44. <https://doi.org/10.1080/03057260108560166>

Sadler, T. (2011). *Socio-scientific issues in the classroom: Teaching, learning and research* (1st ed.). Springer. <https://doi.org/10.1007/978-94-007-1159-4>

Safi, W., Wenzel, T., & Trimble Spalding, L. (2020). Remote learning community: Supporting teacher educators during unprecedented times. *Journal of Technology and Teacher Education*, 28(2), 211–222. <https://doi.org/10.70725/418319ebvimw>

Saldaña, J. (2016). Writing analytic memos about narrative and visual data. In J. Saldaña (Ed.), *The Coding Manual for Qualitative Researchers* (pp. 43-53). Sage.

Saldaña, J., & Omasta, M. (2018). *Qualitative research: Analyzing life*. Sage.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Saunders, K. J., & Rennie, L. J. (2011). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education*, 43(1), 253–274.
<https://doi.org/10.1007/s11165-011-9248-z>
- Savin-Baden, M. (2007). *A practical guide to problem-based learning online*. Routledge.
- Sayer, P., & Braun, D. (2020). The disparate impact of Covid-19 remote learning on English learners in the United States. *TESOL Journal*, 11(3), 1-5. <https://doi.org/10.1002/tesj.546>
- Schirmel, J. (2021). Covid-19 pandemic turns life-science students into “citizen scientists”: Data indicate multiple negative effects of urbanization on biota. *Sustainability*, 13(5), 1–15.
<https://doi.org/10.3390/su13052992>
- Schofield, J. W. (2002). Increasing the generalizability of qualitative research. In J. Schofield (Ed.), *Increasing the generalizability of qualitative research* (pp. 171-203). Sage.
<https://dx.doi.org/10.4135/9781412986274>
- Seaman, J., Brown, M., & Quay, J. (2017). The evolution of experiential theory: Tracing lines of research in the JEE. *Journal of Experiential Education*, 40(4), 1-21.
<https://doi.org/10.1177/1053825916689268>.
- Setyowati, R., Sarwanto, S., & Muzzazinah, M. (2021). How students' higher order thinking skills through e-learning during the Covid-19 pandemic? What does it have to do with university? *Journal of Physics*, 1808(1), 12032–. IOP Publishing.
<https://doi.org/10.1088/1742-6596/1808/1/012032>
- Shanahan, M., & Bechtel, R. (2019). “We’re taking their brilliant minds”: Science teacher expertise, meta-discourse, and the challenges of teacher–scientist collaboration. *Science Education*, 104(2), 354–387. <https://doi.org/10.1002/sce.21550>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Shavelson, R. J., & Webb, N. M. (2009). Generalizability theory and its contribution to the discussion of the generalizability of research findings. In K. Ercikan, & W. M. Roth (Eds.), *Generalizing from educational research: Beyond qualitative and quantitative polarization* (pp. 13 – 32). Routledge. <https://doi.org/10.4324/9780203885376>
- Shi, R., & McLarty, J. W. (2009). Descriptive statistics. *Annals of Allergy, Asthma, & Immunology*, 103(4), S9–S14. [https://doi.org/10.1016/S1081-1206\(10\)60815-0](https://doi.org/10.1016/S1081-1206(10)60815-0)
- Singal, A., Bansal, A., Chaudhary, P., Singh, H., & Patra, A. (2021). Anatomy education of medical and dental students during Covid-19 pandemic: A reality check. *Surgical and Radiologic Anatomy*, 43(4), 515–521. <https://doi.org/10.1007/s00276-020-02615-3>
- Singh-Pillay, A., & Naidoo, J. (2020). Context matters: Science, technology and mathematics lecturers' reflections on online teaching and learning during the Covid-19 pandemic. *Journal of Baltic Science Education*, 19(6A), 1125–1136. <https://doi.org/10.33225/jbse/20.19.1125>
- Sjöström, J., & Talanquer, V. (2014). Humanizing chemistry education: From simple contextualization to multifaceted problematization. *Journal of Chemical Education*, 91(8), 1125–1131. <https://doi.org/10.1021/ed5000718>
- Soares, R., de Mello, M. C. S., da Silva, C. M., Machado, W., & Arbilla, G. (2020). Online chemistry education challenges for Rio de Janeiro students during the Covid-19 pandemic. *Journal of Chemical Education*, 97(9), 3396–3399. <https://doi.org/10.1021/acs.jchemed.0c00775>
- Stephenson, G. (2021, January). One teacher, one job! *The Manitoba Teacher*, 8-9.
- Sullivan, G. M., & Artino, A. R. (2017). How to create a bad survey instrument. *Journal of Graduate Medical Education*, 9(4), 411–415. <https://doi.org/10.4300/JGME-D-17-00375.1>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Taguchi, N. (2020). Digitally mediated remote learning of pragmatics. *Foreign Language Annals*, 53(2), 353–358. <https://doi.org/10.1111/flan.12455>
- Tal, T. (2013). International response for part III: Reflections on context, place-based education and science for all. In J. Bianchini, V. Akerson, A. Calabrese Barton, O. Lee, & R. Rodriguez (Eds.), *Moving the equity agenda forward: Equity research, practice, and policy in science education* (Vol. 5, pp. 211-222). Springer. https://doi.org/10.1007/978-94-007-4467-7_13
- Tashakkori, A., & Creswell, J. W. (2007). Exploring the nature of research questions in mixed methods research [Editorial]. *Journal of Mixed Methods Research*, 1(3), 207–211. <https://doi.org/10.1177/1558689807302814>
- Taylor, T. (2020). Covid-19 and the New Zealand institute of medical laboratory science - a view from the bottom up.” *New Zealand Journal of Medical Laboratory Science*, 74(2), 69.
- Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Sage.
- Thornberg, R., Charmaz, K. (2014). Grounded Theory and Theoretical Coding. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Analysis* (pp. 153–169). Sage. <https://doi.org/10.4135/9781446282243.n11>
- Tienken, C. (2020). The not so subtle inequity of remote learning. *Kappa Delta Pi Record*, 56(4), 151–153. <https://doi.org/10.1080/00228958.2020.1813502>
- Tigaa, R., & Sonawane, S. (2020). An international perspective: Teaching chemistry and engaging students during the Covid-19 pandemic. *Journal of Chemical Education*, 97(9), 3318–3321. <https://doi.org/10.1021/acs.jchemed.0c00554>
- Ting, C., Carin, L., Dzau, V., & Wong, T.Y. (2020). Digital technology and Covid-19. *Nature Medicine*, 26(4), 459–461. <https://doi.org/10.1038/s41591-020-0824-5>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Tire, G. (2025). Estonia: The impact of Covid-19 on education in Estonia—what have we learned from PISA 2022 and national external evaluations? In N. Crato & H. A. Patrinos (Eds.), *Improving national education systems after COVID-19: Moving forward after PIRLS 2021 and PISA 2022* (1st ed., pp. 65-78). Springer. <https://doi.org/10.1007/978-3-031-69284-0>
- Toepoel, V. (2016). *Doing surveys online* (1st ed.). Sage. <https://doi.org/10.4135/9781473967243>
- Tomasik, M., Helbling, L., & Moser, U. (2021). Educational gains of in-person vs. distance learning in primary and secondary schools: A natural experiment during the Covid-19 pandemic school closures in Switzerland. *International Journal of Psychology*, 56(4), 566-576. <https://doi.org/10.1002/ijop.12728>
- Torres-Freyermuth, A., Medellín, G., Martín, G. U., & Puleo, J. A. (2022). A virtual laboratory for conducting “hands-on” experiments on water wave mechanics. *Continental Shelf Research*, 243, 104760–. <https://doi.org/10.1016/j.csr.2022.104760>
- Valladares, L. (2021). Scientific literacy and social transformation: Critical perspectives about science participation and emancipation. *Science & Education*, 30(3), 557–587. <https://doi.org/10.1007/s11191-021-00205-2>
- Valle, J. M., & de Olagüe-Smithson, C. (2021). The Spanish response to the Covid-19 Pandemic: From joint governance to lack of governance. In F. M. Reimers (Ed.), *Primary and secondary education during Covid-19: Disruptions to educational opportunity during a pandemic* (pp. 283–301). Springer. https://doi.org/10.1007/978-3-030-81500-4_11
- van den Hoonaard, D. K. (2019). Ethics on the ground. In D.K. van den Hoonaard (Ed.), *Qualitative research in action: A Canadian primer* (3rd ed., pp. 55-74). Oxford University Press.

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Vannette, D. L., & Krosnick, J. A. (2018). *The Palgrave handbook of survey research*. Springer.

<https://doi.org/10.1007/978-3-319-54395-6>

Vanhorn, S., Ward, S. M., Weismann, K. M., Crandall, H., Reule, J., & Leonard, R. (2019).

Exploring active learning theories, practices, and contexts. *Communication Research Trends*, 38(3), 5-25.

https://scholarcommons.scu.edu/crt/vol38/iss3/1?utm_source=scholarcommons.scu.edu%2Fcr t%2Fvol38%2Fiss3%2F1&utm_medium=PDF&utm_campaign=PDFCoverPages

van Manen, M. (2014). *Phenomenology of practice: Meaning-giving methods in phenomenological research and writing* (1st ed.). Taylor & Francis.

<https://doi.org/10.4324/9781315422657>

Van Nuland, S., Hall, E., & Langley, N. (2020). STEM crisis teaching: Curriculum design with e-learning tools. *FASEB bioAdvances*, 2(11), 631–637. <https://doi.org/10.1096/fba.2020-00049>

Verma, G., Campbell, T., Melville, W., & Park, B. Y. (2020). Science teacher education in the times of the Covid-19 pandemic. *Journal of Science Teacher Education*, 31(5), 483–490.

<https://doi.org/10.1080/1046560X.2020.1771514>

Viviani, F., Ferrari, T., Mussi, M., Zengarini, C., & Orioni, G. (2021). Dermatology residents and Covid-19: Life behind the frontlines. *Clinical and Experimental Dermatology*, 46(1), 169–

170. <https://doi.org/10.1111/ced.14365>

Wang, H.-H.; Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education*, 7(1), Article 3. <https://doi.org/10.1186/s40594-019-0201-4>

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Waight, N., & Neumann, K. (2020). 21st-century science education digital ecologies: Technology, technique, shoelaces, promise, and pitfalls? *Journal of Research in Science Teaching*, 57(9), 1313–1321. <https://doi.org/10.1002/tea.21667>
- Watts, J., Crippen, K. J., Payne, C., Imperial, L., & Veige, M. (2022). The varied experience of undergraduate students during the transition to mandatory online chem lab during the initial lockdown of the Covid-19 pandemic. *Disciplinary and Interdisciplinary Science Education Research*, 4(1), 1–16. <https://doi.org/10.1186/s43031-022-00055-0>
- Wildemuth, B. M. (1993). Post-positivist research: Two examples of methodological pluralism. *The Library Quarterly (Chicago)*, 63(4), 450–468. <https://doi.org/10.1086/602621>
- Withers, M., & Schinske, J. (2016). The college science learning cycle: An instructional model for reformed teaching. *CBE Life Sciences Education*, 15(4), es12-. <https://doi.org/10.1187/cbe.15-04-0101>
- World Health Organization. (2023, June 13). *Emergencies: Coronavirus disease (Covid-19) pandemic*. <https://www.who.int/emergencies/situations/covid-19>
- Worrall, A. F., Bergstrom Mann, P. E., Young, D., Wormald, M. R., Cahill, S. T., & Stewart, M. I. (2020). Benefits of simulations as remote exercises during the Covid-19 pandemic: An enzyme kinetics case study. *Journal of Chemical Education*, 97(9), 2733–2737. <https://doi.org/10.1021/acs.jchemed.0c00607>
- Wu, S., Wyant, D., & Fraser, M. (2016). Author guidelines for qualitative research manuscripts submitted to the journal of the society for social work and research. *Journal of the Society for Social Work and Research*, 7(2), 405–425. <https://doi.org/10.1086/685816>
- Yan, L., Whitelock-Wainwright, A., Guan, Q., Wen, G., Gašević, D., & Chen, G. (2021). Students' experience of online learning during the Covid-19 pandemic: A province-wide

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

survey study. *British Journal of Educational Technology*, 52(5), 2038–2057.

<https://doi.org/10.1111/bjet.13102>

Yang, X., Zhang, M., Kong, L., Wang, Q., & Hong, J. C. (2021). The effects of scientific self-efficacy and cognitive anxiety on science engagement with the “question-observation-doing-explanation” model during school disruption in Covid-19 pandemic. *Journal of Science Education and Technology*, 30(3), 380–393. <https://doi.org/10.1007/s10956-020-09877-x>

Yin, R. (2014). *Case study research: Design and methods* (5th ed.). Sage.

Younas, A., Fàbregues, S., Durante, A., Escalante, E. L., Inayat, S., & Ali, P. (2023). Proposing the “MIRACLE” narrative framework for providing thick description in qualitative research. *International Journal of Qualitative Methods*, 22, Article 16094069221147162. <https://doi.org/10.1177/16094069221147162>

Young, M. E., & Ryan, A. (2020). Post-positivism in health professions education scholarship. *Academic Medicine* 95(5), 695-699. <https://doi.org/10.1097/ACM.0000000000003089>

Youssef, M., McKinstry, E., Dunne, A., Bitton, A., Brady, A. & Jordan., T. (2020). Developing engaging remote laboratory activities for a nonmajors chemistry course during Covid-19. *Journal of Chemical Education*, 97(9), 3048–3054. <https://doi/10.1021/acs.jchemed.0c00792>

Zhang, W., Wang, Y., Yang, L., & Wang, C. (2020). Suspending classes without stopping learning: China's education emergency management policy in the Covid-19 Outbreak. *Journal of Risk and Financial Management*, 13(3), 55-60. <https://doi.org/10.3390/jrfm13030055>

Zoras, B., & Bencze, L. (2014). Utilizing social media to increase student-led activism on STSE issues. In L. Bencze, & S. Alsop (Eds.), *Activist science and technology education* (1st ed., pp. 435–449). Springer. https://doi.org/10.1007/978-94-007-4360-1_24

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Appendix A

Research Ethics Approval Letter



University
of Manitoba

Research Ethics and Compliance

Human Ethics - Fort Garry
208-194 Dafoe Road
Winnipeg, MB R3T 2N2
T: 204 474 8872
humanethics@umanitoba.ca

PROTOCOL APPROVAL

Effective: August 2, 2022

Expiry: August 1, 2023

Principal Investigator: Kathleen Foerster
Advisor: Richard Hechter
Protocol Number: HE2022-0125
Protocol Title: *Pedagogical Response of Manitoba Grade 9 and 10 Science Teachers during the COVID-19 Pandemic: A Mixed Methods Case Study*

Andrea L. Szwajcer, Chair, REB2

Research Ethics Board 2 has reviewed and approved the above research. The Human Ethics Office (HEO) is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans- TCPS 2* (2018).

This approval is subject to the following conditions:

- i. Approval is granted for the research and purposes described in the protocol only.
- ii. Any changes to the protocol or research materials must be approved by the HEO before implementation.
- iii. Any deviations to the research or adverse events must be reported to the HEO immediately through an REB Event.
- iv. This approval is valid for one year only. A Renewal Request must be submitted and approved prior to the above expiry date.
- v. A Protocol Closure must be submitted to the HEO when the research is complete or if the research is terminated.
- vi. The University of Manitoba may request to audit your research documentation to confirm compliance with this approved protocol, and with the UM *Ethics of Research Involving Humans* [Ethics of Research Involving Humans](#) policies and procedures.

Appendix B

Teacher Survey

Demographic Data

1. What is your science teaching experience?
 - ☐ 2 years or less
 - ☐ 3 – 5 years
 - ☐ 6 – 10 years
 - ☐ More than 10 years
2. Which best describes your subject expertise?
 - ☐ Biology
 - ☐ Chemistry
 - ☐ Physics
 - ☐ General Science
 - ☐ Other
3. Where do you currently teach Grade 9 and/or Grade 10 science?
 - ☐ Urban Winnipeg
 - ☐ Urban other
 - ☐ Rural Manitoba
4. Prior to the COVID-19 pandemic, how many times did you teach Grade 9 science in Manitoba?
 - ☐ Never
 - ☐ 1 – 2 times
 - ☐ 3 – 5 times
 - ☐ More than 5 times
5. How many times have you taught Grade 9 science during the COVID-19 pandemic?
 - ☐ None
 - ☐ 1 time
 - ☐ 2 times
 - ☐ 3 or more times
6. Prior to the COVID-19 pandemic, how many times did you teach Grade 10 science in Manitoba?
 - ☐ Never

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- 1 – 2 times
- 3 – 5 times
- More than 5 times

7. How many times have you taught grade 10 science during the COVID-19 pandemic?

- None
- 1 time
- 2 times
- 3 or more times

Research Questions

1. Prior to the pandemic, which best describes the clusters/units you taught in your Grade 9 science classes?

- N/A I did not teach Grade 9 science
- Taught all or most of the learning outcomes in all 4 clusters
- Taught some of the outcomes in all 4 clusters
- Taught all or most of the outcomes in 3 clusters
- Taught some of the outcomes in 3 clusters or less

2. Since the pandemic began in March 2020, which best describes the clusters/units you taught in your Grade 9 science classes with school lockdowns and restrictions?

- N/A I do not teach Grade 9 science
- Taught some of the learning outcomes in 3 clusters or less
- Taught all or most of the outcomes in 3 clusters
- Taught some of the outcomes in all 4 clusters
- Taught all or most of the learning outcomes in all 4 clusters

3. Prior to the pandemic, which best describes the clusters/units you taught in your Grade 10 science classes?

- N/A I did not teach Grade 10 science
- Taught all or most of the learning outcomes in all 4 clusters
- Taught some of the outcomes in all 4 clusters
- Taught all or most of the outcomes in 3 clusters
- Taught some of the outcomes in 3 clusters or less

4. Since the pandemic began in March 2020, which best describes the clusters/units you taught in your Grade 10 science classes with school lockdowns and restrictions?

- N/A I do not teach Grade 10 science
- Taught some of the learning outcomes in 3 clusters or less
- Taught all or most of the outcomes in 3 clusters

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Taught some of the outcomes in all 4 clusters
 - Taught all or most of the learning outcomes in all 4 clusters
5. Prior to the pandemic, what cluster/unit did you prioritize or spend the most time teaching in your Grade 9 science classes?
- N/A I did not teach Grade 9 science
 - Reproduction
 - Atoms and Elements
 - Nature of Electricity
 - Exploring the Universe
6. Since the pandemic began in March 2020, what cluster/unit in your Grade 9 science classes have you prioritized or spent the most time teaching?
- N/A I do not teach Grade 9 science
 - Reproduction
 - Atoms and Elements
 - Nature of Electricity
 - Exploring the Universe
7. Prior to the pandemic, what cluster/unit did you give less priority to, or spend the least time teaching in your Grade 9 science classes?
- N/A I did not teach Grade 9 science
 - Reproduction
 - Atoms and Elements
 - Nature of Electricity
 - Exploring the Universe
8. Since the pandemic began in March 2020, what cluster/unit in your Grade 9 science classes have you given less priority to or spent the least time teaching?
- N/A I do not teach Grade 9 science
 - Reproduction
 - Atoms and Elements
 - Nature of Electricity
 - Exploring the Universe
9. Prior to the pandemic, what cluster/unit did you prioritize or spend the most time teaching in your Grade 10 science classes?
- N/A I did not teach Grade 10 science
 - Ecosystems
 - Chemistry
 - In Motion

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Weather Dynamics
10. Since the pandemic began in March 2020, what cluster/unit in your Grade 10 science classes have you prioritized or spent the most time teaching?
- N/A I do not teach Grade 10 science
 - Ecosystems
 - Chemistry
 - In Motion
 - Weather Dynamics
11. Prior to the pandemic, what cluster/unit did you give less priority to or spend the least time teaching in your Grade 10 science classes?
- N/A I did not teach Grade 10 science
 - Ecosystems
 - Chemistry
 - In Motion
 - Weather Dynamics
12. Since the pandemic began in March 2020, what cluster/unit in your Grade 10 science classes have you given less priority to or spent the least time teaching?
- N/A I do not teach Grade 10 science
 - Ecosystems
 - Chemistry
 - In Motion
 - Weather Dynamics
13. Prior to the pandemic, how often would you engage your Grade 9 or Grade 10 science students in scientific inquiry, debate about scientific issues and/or the design process to solve a technological problem?
- Not at all
 - Not often
 - Occasionally
 - Often
 - Consistently
14. During the pandemic, how often have you engaged your Grade 9 or Grade 10 science students in scientific inquiry, debate about scientific issues and/or or the design process to solve a technological problem?
- Not at all
 - Not often
 - Occasionally

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Often
- Consistently

15. Prior to the pandemic, how focused/centered were you on teaching the general learning outcomes (GLOs) described in Manitoba's Five Foundations for Scientific Literacy: Nature of Science (NOS); Science, Technology, Society and Environment (STSE); Scientific and Technological Skills and Attitudes; Essential Scientific Knowledge and Unifying Concepts?

- Extremely
- Very
- Somewhat
- Not so much
- Not at all

16. During the pandemic, how focused/centered are you on teaching the general learning outcomes (GLOs) described in Manitoba's Five Foundations for Scientific Literacy?

- Extremely
- Very
- Somewhat
- Not so much
- Not at all

17. Prior to the pandemic, how focused/centered were you on teaching the specific or prescribed learning outcomes (SLOs) described in the Manitoba science curriculum documents?

- Not at all
- Not so much
- Somewhat
- Very
- Extremely

18. During the pandemic, how focused/centered are you on teaching the specific or prescribed learning outcomes (SLOs) described in the Manitoba science curriculum documents?

- Not at all
- Not so much
- Somewhat
- Very
- Extremely

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

19. Prior to the pandemic, how focused/centered were you on teaching the Overall Skills and Attitudes learning outcomes described in Cluster 0 of the Manitoba science curriculum documents?
- ☐ Not at all
 - ☐ Not so much
 - ☐ Somewhat
 - ☐ Very
 - ☐ Extremely
20. During the pandemic, how focused/centered are you on teaching the Overall Skills and Attitudes learning outcomes described in Cluster 0 of the Manitoba science curriculum documents?
- ☐ Not at all
 - ☐ Not so much
 - ☐ Somewhat
 - ☐ Very
 - ☐ Extremely
21. In general, how important are practical learning opportunities for your Grade 9 and/or Grade 10 students to develop scientific literacy – concepts, skills and attitudes?
- ☐ Not at all important
 - ☐ Not so important
 - ☐ Somewhat important
 - ☐ Very important
 - ☐ Extremely important
22. During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to experiment, use data collection tools, make measurements, control variables, and/or use WHMIS regulations and safety equipment in your classes?
- ☐ Not at all
 - ☐ Maybe once or twice
 - ☐ Often, but less than before the pandemic
 - ☐ Just as frequently as before
 - ☐ More frequently than before the pandemic
23. During the pandemic lockdowns and restrictions, how often have your Grade 9 and/or Grade 10 students had opportunity to work cooperatively with group members to plan an experiment, carry out the plan, and troubleshoot problems if they arise?
- ☐ More frequently than before the pandemic
 - ☐ Just as frequently as before

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Often, but less than before the pandemic
- Not often, maybe once or twice
- Not at all

24. How confident have you been in your ability to foster scientific literacy – concepts, skills and attitudes in Grade 9 and/or Grade 10 science throughout the COVID-19 pandemic?

- Extremely confident
- Very confident
- Somewhat confident
- Not very confident
- Not confident at all

25. Prior to the COVID-19 pandemic, which of the following skills and attitudes specific learning outcomes did you adequately explore with your students in your Grade 9 and/or Grade 10 classes? (Select all that apply)

- Propose questions to be tested experimentally
- Identify stakeholders and initiate research related to a scientific issue
- Select, integrate, summarize and evaluate information
- Identify mathematical relationships between variables
- Plan an experiment to answer a specific scientific question
- Carry out procedures to control variables and repeat experiments for increased accuracy and reliability
- Understand WHMIS and MSDS, and demonstrate work habits that ensure safety for self and others with consideration for the environment
- Work cooperatively with group members to carry out a plan and troubleshoot problems as they arise
- Select and use appropriate methods and tools for measuring and collecting data
- Record, organize and display data to look for trends and discrepancies
- Discuss science and technology, and appreciate and respect cultural contributions throughout history
- Discuss social, economic, and environmental effects of past and present scientific and technological endeavors
- Demonstrate interest and personal involvement in STSE (science, technology, society and environment) issues, and relate personal activities and career choices to scientific disciplines
- Demonstrate confidence in ability to carry out scientific investigations and address STSE issues
- Value skepticism, honesty, accuracy precision, perseverance, and open-mindedness, and be sensitive and responsible to human needs and a sustainable environment

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

26. Since the start of the COVID-19 pandemic in March 2020, which of the following skills and attitudes specific learning outcomes have you adequately explored with lockdowns and/or restrictions in your Grade 9 and/or Grade 10 classes? (Select all that apply)

- Propose questions to be tested experimentally
- Identify stakeholders and initiate research related to a scientific issue
- Select, integrate, summarize and evaluate information
- Identify mathematical relationships between variables
- Plan an experiment to answer a specific scientific question
- Carry out procedures to control variables and repeat experiments for increased accuracy and reliability
- Understand WHMIS and MSDS, and demonstrate work habits that ensure safety for self and others with consideration for the environment
- Work cooperatively with group members to carry out a plan and troubleshoot problems as they arise
- Select and use appropriate methods and tools for measuring and collecting data
- Record, organize and display data to look for trends and discrepancies
- Discuss science and technology, and appreciate and respect cultural contributions throughout history
- Discuss social, economic, and environmental effects of past and present scientific and technological endeavors
- Demonstrate interest and personal involvement in STSE (science, technology, society and environment) issues, and relate personal activities and career choices to scientific disciplines
- Demonstrate confidence in ability to carry out scientific investigations and address STSE issues
- Value skepticism, honesty, accuracy precision, perseverance, and open-mindedness, and be sensitive and responsible to human needs and a sustainable environment

27. Prior to the COVID-19 pandemic, which of the following specific learning outcomes did you teach through “hands-on” learning activities/practical work in your Grade 9 science classes? (Select all that apply if you taught Grade 9 science)

Reproduction:

- Illustrate and explain the process of mitotic cell division in plants and animals
- Investigate and describe agricultural applications of asexual reproduction
- Compare and contrast the function of mitosis to meiosis
- Investigate and explain adaptations of plant and animal species which enhance reproductive success
- Observe, collect and analyze class data of single trait inheritance
- Use a pedigree to track the inheritance of a single trait
- Investigate environmental factors and personal choices that may lead to genetic mutations

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Discuss current and potential applications and implications of biotechnologies including genetic engineering, genetic screening, cloning and DNA fingerprinting

Atoms and Elements:

- Assemble or draw Bohr atomic models for the first 18 elements
- Investigate the development of the periodic table as a method of organizing elements
- Investigate the characteristic properties of metals, non-metals and metalloids like ductility, lustre and reactivity, and classify elements according to these properties
- Relate the reactivity and stability of different families of elements to their atomic structure
- Investigate properties of substances like durability, usefulness and safety, and explain the importance of knowing these properties
- Differentiate between physical and chemical changes
- Experiment to determine indicators of chemical change
- Investigate technologies and natural phenomena that demonstrate chemical change in everyday situations

Nature of Electricity:

- Demonstrate evidence for the existence of two types of charge
- Explain how a discrepant event can be used to evaluate the particle model of electricity
- Investigate and explain electrostatic phenomena like conduction, induction and grounding using the particle model of electricity
- Investigate common electrostatic technologies and phenomena like photocopying and electrostatic spray-painting and safety measures like static straps
- Construct one or more electrostatic apparatus like a pie-plate electrophorus, and explain how they function
- Demonstrate and explain the like nature of electrostatics and current electricity including discharging an electrophorus through a neon bulb
- Construct electric circuits in series and parallel using schematic diagrams
- Use appropriate instruments and units to measure voltage, current and resistance
- Compare and contrast voltage and current in series and parallel circuits, including cells and resistance
- Investigate and describe qualitatively the relationship among current, voltage and resistance in a simple circuit
- Relate the energy dissipated in a circuit to the resistance, current and brightness of bulbs
- Explain the parallel circuits, components including switches, fuses, outlets and circuit breakers, and the safety aspects of household wiring
- Analyze the electrical energy consumption of a household appliance, including EnerGuide consumption and reading hydro meters

Exploring the Universe:

- Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects with altitude and azimuth

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Observe the motion of visible celestial objects and organize collected data, such as tracking the position of the moon and planets over time or tracking sunrise and sunset data
- Explain the apparent motion of the Sun, stars, planets, and the Moon as seen from Earth including daily rising and setting, seasonal constellations and retrograde motion
- Investigate Canada's role in space research and international programs like the International Space Station (ISS) and Canadarm, and use the decision-making process to address a related issue
- Evaluate the impact of space science and technologies in terms of their benefits and risks to humans

28. Since the start of the pandemic in March 2020, which of the following specific Grade 9 learning outcomes did/do you teach using different/alternative learning activities not “hands-on”/don't involve practical work? (Select all that apply if you taught Grade 9 science)

Reproduction:

- Illustrate and explain the process of mitotic cell division in plants and animals
- Investigate and describe agricultural applications of asexual reproduction
- Compare and contrast the function of mitosis to meiosis
- Investigate and explain adaptations of plant and animal species which enhance reproductive success
- Observe, collect and analyze class data of single trait inheritance
- Use a pedigree to track the inheritance of a single trait
- Investigate environmental factors and personal choices that may lead to genetic mutations
- Discuss current and potential applications and implications of biotechnologies including genetic engineering, genetic screening, cloning and DNA fingerprinting

Atoms and Elements:

- Assemble or draw Bohr atomic models for the first 18 elements
- Investigate the development of the periodic table as a method of organizing elements
- Investigate the characteristic properties of metals, non-metals and metalloids like ductility, lustre and reactivity, and classify elements according to these properties
- Relate the reactivity and stability of different families of elements to their atomic structure
- Investigate properties of substances like durability, usefulness and safety, and explain the importance of knowing these properties
- Differentiate between physical and chemical changes
- Experiment to determine indicators of chemical change
- Investigate technologies and natural phenomena that demonstrate chemical change in everyday situations

Nature of Electricity:

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Demonstrate evidence for the existence of two types of charge
- Explain how a discrepant event can be used to evaluate the particle model of electricity
- Investigate and explain electrostatic phenomena like conduction, induction and grounding using the particle model of electricity
- Investigate common electrostatic technologies and phenomena like photocopying and electrostatic spray-painting and safety measures like static straps
- Construct one or more electrostatic apparatus like a pie-plate electrophorus, and explain how they function
- Demonstrate and explain the like nature of electrostatics and current electricity including discharging an electrophorus through a neon bulb
- Construct electric circuits in series and parallel using schematic diagrams
- Use appropriate instruments and units to measure voltage, current and resistance
- Compare and contrast voltage and current in series and parallel circuits, including cells and resistance
- Investigate and describe qualitatively the relationship among current, voltage and resistance in a simple circuit
- Relate the energy dissipated in a circuit to the resistance, current and brightness of bulbs
- Explain the parallel circuits, components including switches, fuses, outlets and circuit breakers, and the safety aspects of household wiring
- Analyze the electrical energy consumption of a household appliance, including EnerGuide consumption and reading hydro meters

Exploring the Universe:

- Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects with altitude and azimuth
- Observe the motion of visible celestial objects and organize collected data, such as tracking the position of the moon and planets over time or tracking sunrise and sunset data
- Explain the apparent motion of the Sun, stars, planets, and the Moon as seen from Earth including daily rising and setting, seasonal constellations and retrograde motion
- Investigate Canada's role in space research and international programs like the International Space Station (ISS) and Canadarm, and use the decision-making process to address a related issue
- Evaluate the impact of space science and technologies in terms of their benefits and risks to humans

29. Prior to the COVID-19 pandemic, which of the following specific learning outcomes did you teach through “hands-on” learning activities/practical work in your Grade 10 science classes? (Select all that apply if you taught Grade 10 science)

Ecosystems:

- Illustrate and explain how carbon, nitrogen, and oxygen are cycled through an ecosystem

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

- Construct and interpret graphs of population dynamics
- Observe and document a range of organisms that illustrate the biodiversity within an ecosystem
- Investigate how human activities affect an ecosystem and use the decision-making process to propose a course of action to enhance its sustainability

Chemistry:

- Investigate the Law of Conservation of Mass, and recognize that mass is conserved in chemical reactions
- Investigate and classify reactions as synthesis, decomposition, single displacement, double displacement, or combustion
- Experiment to classify acids and bases, using pH and indicators
- Investigate technologies used to reduce emissions

In Motion:

- Analyze the relationship among displacement, time and velocity for an object in uniform motion
- Collect displacement data to calculate and graph velocity versus time for an object that is accelerating at a constant rate
- Analyze the relationships among velocity, time and acceleration for an object that is accelerating at a constant rate
- Experiment to illustrate the effects of inertia in car collisions
- Investigate and describe qualitatively Newton's Third Law
- Investigate conditions that illustrate the effects of friction on motion such as surface materials
- Investigate the factors that influence braking distance

Weather Dynamics:

- Explain effects of heat transfer within the atmosphere and hydrosphere on the development and movement of wind and ocean currents
- Collect, interpret and analyze meteorological data related to a severe weather event

30. Since the start of the pandemic in March 2020, which of the following specific grade 10 learning outcomes did/do you teach using different/alternative learning activities not "hands-on"/don't involve practical work? (Select all that apply if you taught grade 10 science)

Ecosystems:

- Illustrate and explain how carbon, nitrogen, and oxygen are cycled through an ecosystem
- Construct and interpret graphs of population dynamics
- Observe and document a range of organisms that illustrate the biodiversity within an ecosystem
- Investigate how human activities affect an ecosystem and use the decision-making process to propose a course of action to enhance its sustainability

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

Chemistry:

- Investigate the Law of Conservation of Mass, and recognize that mass is conserved in chemical reactions
- Investigate and classify reactions as synthesis, decomposition, single displacement, double displacement, or combustion
- Experiment to classify acids and bases, using pH and indicators
- Investigate technologies used to reduce emissions

In Motion:

- Analyze the relationship among displacement, time and velocity for an object in uniform motion
- Collect displacement data to calculate and graph velocity versus time for an object that is accelerating at a constant rate
- Analyze the relationships among velocity, time and acceleration for an object that is accelerating at a constant rate
- Experiment to illustrate the effects of inertia in car collisions
- Investigate and describe qualitatively Newton's Third Law
- Investigate conditions that illustrate the effects of friction on motion such as surface materials
- Investigate the factors that influence braking distance

Weather Dynamics:

- Explain effects of heat transfer within the atmosphere and hydrosphere on the development and movement of wind and ocean currents
- Collect, interpret and analyze meteorological data related to a severe weather event

Appendix C

Teacher Interview Protocol

1. How does your experience teaching Grade 9 or 10 science prior to the COVID-19 pandemic generally compare with teaching these courses during the pandemic?
2. Prior to the pandemic, did you teach all four units/clusters in the Grade 9 course (Reproduction, Atoms and Elements, Nature of Electricity, Exploring the Universe) and/or in the Grade 10 course (Ecosystems, Chemistry, Motion, Weather); and which clusters did you prioritize or spend more time teaching, and which ones were given lower priority?
3. Prior to the pandemic, did you try to teach all learning outcomes in the Grade 9 and/or 10 course, including concepts, skills and attitudes? For instance, in Grade 9 Reproduction did your class observe, collect and analyze data of single trait inheritance; or discuss the implications of biotechnologies; or use the decision-making process to address a current biotechnology issue? Or in Grade 10 Chemistry for example, did your students investigate the conservation of mass in a laboratory activity; or perform experiments to investigate the five types of chemical reactions?
4. Prior to the pandemic did you prioritize any learning outcomes in your Grade 9 and/or Grade 10 science classes or leave any out, and if so, what were your reasons for doing so?
5. Since the pandemic began in March 2020, which, if any clusters in your Grade 9 and/or Grade 10 science classes have you given higher or lower priority, and what have you considered when making these decisions?
6. Since the pandemic began in March 2020, have your priorities of specific learning outcomes that you teach in Grade 9 and/or Grade 10 science changed? If so, which learning outcomes are now given higher or lower priority – specific concepts like atoms and compounds in Grade 9 chemistry; or general skills and attitudes like addressing safe driving conditions in Grade 10 motion; and what are your reasons for this adjustment?
7. What specific teaching modes have you experienced since the start of the pandemic – remote/online, blended, synchronous/asynchronous, full classes with restrictions, other; and how has each mode affected what you choose to teach, and how you teach?
8. How do the types of learning activities you provide for your Grade 9 and Grade 10 students compare before and during the pandemic?

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

9. Overall, how have restrictions to practical learning opportunities affected your ability to teach Grade 9 and/or Grade 10 science throughout the pandemic, and how do you think your response to restrictions has affected your students' ability to learn science?
10. During the pandemic, how important is it for you to promote the general learning outcomes (GLOs) and specific skills and attitudes learning outcomes in Cluster 0 of the Manitoba science curriculum documents in Grade 9 and/or Grade 10 science?
11. During the pandemic, how important is it to promote science concepts described in the specific or prescribed learning outcomes found in the Manitoba science curriculum documents, such as defining voltage in Grade 9 science, or describing bioaccumulation in Grade 10 science?
12. Prior to the pandemic, how often might you engage your Grade 9 and/or Grade 10 students in a hands-on practical learning activity, and what are examples of such activities?
13. Have you created and/or implemented alternative learning activities to replace the traditional practical ones limited by school lockdowns and restrictions, and if so, what are some examples?
14. Do you think that these alternative learning activities have been effective for advancing concepts, skills and attitudes necessary for scientific literacy, and that students – at least some students demonstrated evidence of growth in these areas? For example, have they demonstrated improved inquiry, problem solving, critical thinking and decision-making abilities?
15. What types of adjustments have you made in your teaching approach since the pandemic began, with consideration to oral presentations, demonstrations, laboratory or hands-on learning activities, class discussions, student project work, research or written assignments?
16. Have you made changes to your assessment practices in Grade 9 and/or Grade 10 science throughout the pandemic, and if so, what changes have you made and why have you made them?
17. How does student performance and achievement in Grade 9 and/or Grade 10 science generally compare before and during the pandemic, and are any particular changes in learning apparent?
18. What impact do you think the pandemic might have on the overall development of student scientific literacy – concepts, skills and attitudes, and as such how prepared are your Grade 9 and/or Grade 10 students for their next course/level in science?

SCIENCE TEACHERS' PEDAGOGICAL RESPONSE DURING COVID-19

19. Reflecting back to March 2020, would you make any changes to what you teach or how you teach Grade 9 and/or Grade 10 science during the pandemic, and if so, what would you change and why?
20. Has your Grade 9 and/or Grade 10 science teaching experience through COVID-19 affected your future teaching practices for Grade 9 and/or Grade 10 science, and if so, in what way?

Appendix D**Table D1.***Abbreviations Used in this Study*

Biological Sciences Curriculum Study	BSCS
Blended Learning	BL
Council for Education and Teaching	ICET
General Learning Outcome(s)	GLO / GLOs
Learning Outcome(s)	LO / LOs
Manitoba Education and Training	MET
Nature of Science	NOS
Place-based Education	PBE
Privacy Training for Researchers	PHIA
Project-based Learning	PBL
Science Curriculum Improvement Study	SCIS
Science, Technology, Society and the Environment	STSE
Scientific Inquiry	SI
Socio-scientific Issues	SSI
Specific Learning Outcome(s)	SLO / SLOs
Tri-Council Policy Statement Course on Research Ethics	TCPS 2: CORE
United States	U.S.
Workplace Hazardous Materials Information System	WHMIS

Appendix E

Table E1.

Code Groups, Codes and Abbreviations used in Transcript Analysis

Code Group Codes and Abbreviations			Code Group Codes and Abbreviations		
School Structure	Manitoba Education	ME	Educational Foundations	curriculum	C
	government decisions	gov		unit/cluster	unit
	administration	ad		specific LOs	SLOs
	safety	S*		general LOs	GLOs
	pandemic mode	t		cluster 0 SLOs	0!
Teacher Experiences	relationships	R	Resources	equipment/material	eqp
	mental/physical health	H		technology	tech
	dedication	ded		time	24h
	practical work	Pw		teacher supports	t+
	difficulty/concerns	D!		teacher training	tt
	development/growth	grw	Learning Impacts	scientific literacy	SL
Teaching Science	teacher approach/style	T*		concepts	con
	instructional mode	im		skills/attitudes	sk/att
	priorities	NB		knowledge gaps	G?
	expectations	x↓		critical thinking	CT
	restrictions	RX		motivation	mot
	student engagement	Sng		benefits	B?
	assessment	gd		student supports	SS!!
	alternatives/adjustments	alt		future needs	fuN