Connecting Epistemic Beliefs about Physics Knowledge and Curriculum Concerns in Saskatchewan: A Mixed Analysis Study

by

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ABSTRACT

According to the Saskatchewan Ministry of Education, curriculum documents indicate what is to be learned by students by the end of a school year. As Canadian provincial governments mandate new curriculum documents, it is assumed that teachers will teach these courses as indicated. Despite teachers' familiarity with change, they commonly raise concerns regarding new curriculum documents. Yet, what influences these concerns? Conceiving of epistemic beliefs about physics knowledge as a filter with which teachers read and interpret curriculum documents, this study investigated whether teachers' concerns regarding a new curriculum document could be connected to epistemic beliefs. This study contributes to the thin literature investigating teachers' epistemic beliefs about physics knowledge and provides a contextual study about teachers' concerns in Saskatchewan, Canada.

In this study, I intended to use data from both quantitative surveys and qualitative interviews. Unfortunately, the literature informed survey proved not to be valid for measuring teachers' epistemic beliefs about physics knowledge. Similar issues were found with the survey used to try to measure teachers' concerns. Ultimately, data for this study came from interviewing 16 physics teachers across the Western Canadian province of Saskatchewan regarding their, (a) epistemic beliefs about physics knowledge, and (b) concerns about a recently-released grade 12 physics curriculum document. Interviews were transcribed and then coded using thematic analysis. Results from coding were analyzed for potential connections between teachers' epistemic beliefs about physics knowledge and their concerns. Visual representations including Venn diagrams and matrices were used.

Findings from this study suggest that teachers' epistemic beliefs about the source and content of physics knowledge could be connected to their concerns about the grade 12 Physics curriculum document in Saskatchewan released in 2017. Findings also point to the influence of the unique accreditation system that Saskatchewan uses to determine whether a student must write a provincial exam in physics. This study presents a case for: (a) further investigation into teachers' epistemic compatibility with mandated teaching resources, particularly since their epistemic beliefs about physics knowledge did not necessarily reflect those epistemic beliefs expressed by physicists and scholars of the epistemology of science; (b) the development of a community focused on connecting Saskatchewan physics teachers since these teachers could feel isolated in their roles; and (c) curriculum documents be made readable and interpretable for teachers with varying epistemic beliefs so that they are able to teach the course as intended, particularly when preparing students for a provincial examination.

PREFACE

This thesis is an original work by Ellen Watson. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "CURRICULUM CHANGE, CONCERNS, AND BELIEFS ABOUT KNOWLEDGE: EXPLORING CURRICULUM IMPLEMENTATION IN SASKATCHEWAN", Pro00075325, Dec. 7, 2017.

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DEDICATION

I dedicate this thesis to all of the teachers willing to reflect critically on the system in which they are employed. The teachers willing to raise their voices in a system that expects them to teach as they are told. Those teachers willing to push the boundaries and be the intelligent media of action they are meant to be. I hope this research opens a door for you to continue to push for change.

"*It is [...] advisable that the teacher should understand, and even be able to criticize the general principles upon which the whole educational system is formed and administered. He [sic] is not like a private soldier in an army, expected to merely respond to and transmit external energy; he must be an intelligent medium of action,"* John Dewey, 1895 (as cited by Goldstein, 2014, p.1)

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CHAPTER 1: INTRODUCTION AND PURPOSE

1.1. Reasons for Proposing This Study

Following the *Directions* report (Saskatchewan Education, 1984), and created by the Curriculum and Instruction Review Committee, the previously used (or past) Saskatchewan Physics 30 curriculum document was released in 1992. When I began teaching in Saskatchewan schools in the fall of 2008, I was working from this already 16-year-old document. Eventually, the Saskatchewan Ministry of Education reconsidered their K – 12 science curricula and began rewriting these curriculum documents shortly after the release of the Pan Canadian Framework (CMEC, 1997) in the late 1990s. The grade 12 sciences (Physics 30, Chemistry 30, and Biology 30) were the last to be updated. After teaching high school physics from 2008 - 2013, I was given the opportunity to contribute as one of four teacher-writers for the Physics 30 curriculum document[1] for use in Saskatchewan schools. The Physics 30 curriculum document was first made available in the fall of 2016 and teachers had the option to teach from this document or the 1992 Physics 30 curriculum document in the 2016 – 2017 school year. A final (revised) version of the updated curriculum document for Physics 30 was released in the fall of 2017 and the 1992 Physics 30 document was officially retired.

Upon entering the profession and preparing to teach, I attempted to interpret the 1992 Physics 30 curriculum to the best of my ability. The 1992 Physics 30 curriculum required 244 learning outcomes in four core units be attended to, plus the outcomes in at least one optional

[1] The curriculum document, also referred to as "the curriculum", in Saskatchewan refers to the document defining the content to be covered. This terminology is consistent with that used in British Columbia, Manitoba, New Brunswick, Nova Scotia, Prince Edward Island, Ontario, and Yukon. This document is analogous to the Program of Studies used in Alberta, the Northwest Territories, and Nunavut, the Education Program in Quebec, and the Curriculum Guides in Newfoundland and Labrador.

unit (Saskatchewan Education, 1992). These learning outcomes commonly called for tasks such as solving problems using specific methods, defining terms, identifying physical principles, calculation, and stating various laws. For example, one outcome listed was "recognize the importance of free body diagrams in analyzing problems in physics dealing with statics and dynamics," (Saskatchewan Education, 1992, p. 181). To achieve that outcome, students were expected to analyze problems using free-body diagrams; later, students were asked to solve statics and dynamics problems using vector addition. Further examples of outcomes from the 1992 document can be found in Appendix A. These requests—to me—ignored those learning outcomes more pertinent to how I conceptualized physics knowledge. What I believed to be important in the teaching and learning of physics included asking students to explain relationships, develop and show evidence of a conceptual, qualitative understanding, and explore physics beyond completing algorithmic calculations. I was not alone in this view. My fellow teacher-writers contributing to the new Physics 30 curriculum document also sought to develop a physics curriculum document that better represented this conceptualization of physics knowledge. Thus, we worked to change the curriculum to reflect such orientations.

Inevitably, school curricula are bound to change. The collective knowledge of the peoples of the world is constantly changing. Consequently, it is important to revise science curricula to reflect contemporary scientific discoveries and understandings of the nature of science. Milford et al. (2010) argued that the Pan Canadian Framework was outdated, but I contend that its focus on scientific literacy is not—as supported by Molnar et al. (2019). Yet, scientific literacy can come in many forms. For us, the teachers writing the 2017 Saskatchewan Physics 30 curriculum document, developing scientific literacy meant engaging students with scientific ideas and relevant concepts to support them in developing an analytical approach with which to understand the world. This explanation of scientific literacy is similar to those aspects required by the Pan Canadian Framework (CMEC, 1997). Our teacher-writer team wanted the 2017 Saskatchewan Physics 30 curriculum to prepare students to discuss physics concepts and topics, particularly topics regarding current and emerging ideas within physics. As has been suggested by Brahmia (2014) and Karam et al. (2019), we too felt that focusing physics courses on complex mathematics might overwhelm some students, potentially turning them away from studying physics. Hence, we sought to design outcomes and indicators in the 2017 Physics 30 curriculum document that portrayed physics as conceptually focused and with a coherent structure of knowledge. Our orientation represented a shift from the item-focused and algorithmic 1992 Physics 30 curriculum document.

In our first meeting as teacher-writers for the Physics 30 curriculum, we decided to remove a large part of the mathematics-focused concepts from the curriculum and focus on what we believed to best represent physics knowledge. To us, learning physics "implie[d] learning the concepts, principles and the structure of physics as well as the use of scientific methods including mathematic[s]," (Pospiech, 2019, p.1). Therefore, we did not remove all mathematics-based physics. Rather, we tried to orient most of the document toward conceptual physics[2]. Two units (known as 'modern physics' and 'fields' by Saskatchewan teachers) that heavily emphasized conceptual physics were included in the 2017 Physics 30 curriculum to reflect our focus on conceptual-physics, increase students' interest, minimize students' struggles in physics 'caused by mathematics', and promote the physics we conjectured students should know when

[2] The terms 'mathematics-based' physics and 'conceptual' physics are commonly used when researching physics education (e.g., Brahmia, 2014; Hammer, 1994; Bigozzi et al., 2018; Pospiech et al, 2019). Mathematics-based physics commonly refers to using formulae (and mathematical relationships) to solve problems whereas conceptual physics refers to qualitative and intuitive solutions to problems.

they finished a grade 12 physics course in Saskatchewan. Our writing team knew this curriculum change would likely raise some concerns with teachers, but we had a vision and produced a document with nine learning outcomes supported by 97 suggested indicators.

A noticeable change to those science curriculum documents written since 2010 (at least compared to the previously used Saskatchewan science curriculum documents) included using mandatory, overarching outcomes supported by a number of suggested indicators (Saskatchewan Ministry of Education, 2010). Indicators, while not mandated, provided some direction to teachers regarding the "ways that students might demonstrate achievement of an outcome and clarify the breadth and depth of each outcome," (Molnar et al., 2019); indicators represented those topics that could reflect an understanding of an outcome. This differed from the required learning outcomes presented in the 1992 Physics 30 curriculum document. One of the outcomes within the 2017 Saskatchewan Physics 30 curriculum and its' representative indicators are shown in Table 1. Also noted within Table 1 are the areas of scientific literacy each indicator can support: "K" represents science knowledge (or content), "STSE" represents science, technology, society, and environment, and "S" represents science skills. "SI" represents the learning context of scientific inquiry to be emphasized in this unit. These areas of scientific literacy are derived from the Pan Canadian Framework and are common to all science curriculum documents in Saskatchewan.

According to the outcome and indicator layout shown in Table 1, after completing Physics 30 in Saskatchewan students should be able to "analyze the motion of objects and interactions between objects using momentum concepts, including the law of conservation of momentum," (Saskatchewan Ministry of Education, 2017, p. 30). As the outcomes in this document are often imprecise, indicators (in this case a – g) are used to give teachers ideas of

Table 1

Example Outcome and Indicators (Saskatchewan Ministry of Education, 2017, p. 30)

PH30-CO2 Analyze the motion of objects and interactions between objects using momentum concepts, including the law of conservation of momentum. [SI]	a. Explore how impulse and momentum concepts apply to motion-related technologies in fields such as sports science, transportation and space science. (STSE) b. Derive the formula for impulse from Newton's second law of motion. (S) c. Investigate how changing the net force applied to an object or the amount of time the force is applied affect the momentum of an object, with reference to the formula $\vec{F}\Delta t = m\Delta\vec{v}$ (S) d. Provide examples that show how momentum is or is not conserved in everyday situations. (K) e. Conduct an experiment or simulation, including collecting, analyzing and interpreting data, to determine the extent to which momentum is conserved in elastic and inelastic collisions. (STSE, S) f. Solve problems using the law of conservation of momentum in one- and two-dimensional interactions (e.g., head-on collisions, glancing collisions, rocket launches and explosions). (K, S) g. Analyze applications (e.g., neutrino detection, Large Hadron Collider, crash test dummies and personal safety devices) of the law of conservation of momentum. (STSE)

specific skills, activities, or experiences students could encounter to achieve these outcomes. Indicators such as these gave teachers an idea of what might constitute evidence of students achieving an outcome; the teacher is not expected to attend to every indicator but should use these to guide their decisions on instruction and assessment. "Indicators are included to provide the breadth and depth of what students should know and be able to achieve the learning outcomes," (Ministry of Education, 2017, p. 3). Further comparison between the 1992 and 2017 Saskatchewan Physics 30 curriculum documents is provided in Chapter 2.

A significant reduction in the number of indicators, the removal of many beloved units (such as 'circuit analysis' and 'graphical kinematics'), and a change in epistemic orientation of the Physics 30 curriculum document quickly led to physics teachers voicing concerns across the province. Informally, my colleagues and I spoke with teachers who appreciated the change, as well as those wary of the 2017 Physics 30 curriculum document. Some teachers were less than satisfied with the included topics—particularly 'fields'—as well as the descriptors used in outcomes in the 2017 curriculum document. Yet, some teachers were excited to discuss ideas that had been more recently accepted by the physics community. Some teachers were concerned about the time it would take to 'cover' all this material while some were concerned there was no longer enough substance to the Physics 30 curriculum document. I wondered, "What was driving these anxieties?" and "What were teachers commonly concerned about and what was causing these concerns?" After informally encountering these concerns, I proposed that exploration of teacher concerns regarding the 2017 Saskatchewan Physics 30 curriculum document was warranted.

1.2. Rationale and Significance of Research

As a classroom teacher who was forced to teach through major changes to curricula, such as the changes to Saskatchewan's Mathematics curriculum to match the *Western and Northern Canadian Protocol*, I have both noticed and experienced an initial period of resistance to new curricula. Colleagues and students' parents expressed concern with the content of the mathematics curriculum released between 2007 and 2012 in Saskatchewan, claiming it removed 'basic' mathematics knowledge (Abtahi & Barwell, 2019; Chernoff, 2019). I had seen similar patterns emerging among physics teachers as they engaged with the 2017 Physics 30 curriculum document.

Physics 30 teachers were expressing concerns, but I wondered what was driving these concerns. Maybe it was that teachers questioned their current epistemic beliefs about physics knowledge in light of the 2017 curriculum and, consequently, they raised concerns about the 2017 curriculum document to avoid putting themselves in a vulnerable situation, as Le Fevre (2014) suggested might occur. Perhaps, as noted by Tytler (2010), teachers saw themselves as the protectors of the content to be taught in Physics 30 and considered it their duty to hold fast the content of the 1992 curriculum. It may be that resistance surfaced because teachers were uncertain about what the 2017 curriculum document meant for their instruction, as both Le Fevre (2014) and van den Berg and Ros (1999) have identified. I wondered whether the concerns of teachers, and resulting resistances, were connected, at least in some part, to differences their epistemic beliefs about physics knowledge.

1.2.1. Adding to the Literature on Epistemic Beliefs

Epistemic beliefs about science knowledge have been studied in their relation to other phenomena such as metacognition (e.g., Muis, 2008; Muis et al., 2018; Yavuz, 2014), performance and motivation (e.g., Buehl & Alexander, 2005), understanding of physics equations (e.g., Domert et al., 2007), and, most commonly, teacher beliefs about the practice, teaching, and learning of science (e.g., Enriquez, 2019; Leng et al., 2018; Merk et al., 2019; Markic & Eilks, 2012; Tsai, 2006). However, epistemic beliefs have yet to be studied in depth in relation to curriculum implementation. This study begins to address this gap in the literature and, as a result, intended to help the educational community better understand teacher approaches to engaging with revisions to content in government mandated, course curriculum documents.

Recently, educational researchers in the field of epistemic beliefs have begun exploring connections between students' interactions with epistemic activities and resulting epistemic emotions (see Pekrun et al., 2017; Muis et al., 2015; Muis et al., 2018; Rosman & Mayer, 2018). In these studies, epistemic emotions are commonly defined as emotions arising from the compatibility, or incompatibility, between the epistemic beliefs of the reader and the activity with which they interact (Muis et al., 2018). I propose that the same may be true for teachers. When teachers interact with any document with an underlying epistemic orientation—such as can be found in any curriculum document—they experience epistemic emotions, some of which might be described as what I am calling *concerns*. Combining research from the fields of epistemic beliefs and teacher concerns, this study might provide early steps into exploring the epistemic emotions of teachers and how these emotions inform their teaching of physics. Studies exploring this epistemic incompatibility are becoming increasingly more common with students, but literature has yet to meaningfully explore this phenomenon with teachers.

1.2.3. Contributing to Research About Teacher Concerns

Teacher concerns regarding the implementation of curricula have been studied in senior sciences in Hong Kong (e.g., Geng et al., 2019), Israel (e.g., Gabby et al., 2017), South Africa (e.g., Gudyanga & Jita, 2018), the United Kingdom (e.g., Ryder & Banner, 2014; Ryder et al., 2014), and the United States of America (e.g., Boergerding et al., 2013). Teacher concerns have also been studied in subjects other than science including mathematics (e.g., Charalambous & Philippou, 2010; Christou et al., 2004; Tunks & Weller, 2009) and liberal studies (e.g., Kwok, 2014). Still, there remains a lack of studies analyzing high school science curriculum implementation as related to teacher concerns in a Western Canadian context.

It should be noted that the word 'concern' does limit this study; I chose to use this term for consistency with the Stages of Concern framework being used (see Chapter 4). In future studies, I would suggest investigating the emerging area of 'epistemic emotions', drawing on recent educational studies such as Pekrun et al. (2017), Muis et al. (2018) and Rosman & Mayer (2018), to allow room for the exploration of a variety of emotions including worries and anxieties (what we colloquially call concerns) but also positive emotional experiences such as joy and hope.

It should be clarified that it was not the intent of this study to analyze the epistemic orientation of the new Physics 30 curriculum document, as this activity could be the basis of an entire thesis. Rather, this study intended to view teachers' epistemic beliefs about physics knowledge and their concerns about a new curriculum document in parallel so as to determine areas of concern (teachers' epistemic emotions) which may be informed by certain epistemic orientations. However, it may be of interest for future research to explore connections between teachers' epistemic beliefs about the knowledge informing a subject of instruction and those epistemic emotions that surface when encountering curriculum documents or teaching materials that either support or debate their beliefs.

1.2.3. Supporting Teachers During Educational Change in Western Canada

Canada is one of the few countries who consistently perform well in the Programme for International Student Assessment without a nationally-mandated curriculum (Milford & Tippett, 2019). Since those studies investigating teachers' concerns typically occur with a nationally-mandated curriculum document, this study provided insight into teachers' concerns with a more context-specific curriculum document—this context being Saskatchewan. There is also a lack of literature investigating teachers' concerns in relation to changes in physics education as most studies focus on science education in general. This research provides a contextual understanding of Saskatchewan Physics teachers' concerns with regards to the adoption of a high school physics curriculum, particularly as these concerns relate to their epistemic beliefs about physics knowledge.

Knowing reasons for teachers' reactions toward curriculum change could potentially shed light on how to mitigate teachers' discomfort during a change in science curricula. By investigating teachers' concerns regarding the implementation of the 2017 Saskatchewan Physics

30 curriculum document, particularly as they relate to epistemic beliefs about physics knowledge, I sought to uncover possible reasons for resistance to curriculum implementation within that context. Understanding possible reasons for resistance might assist teachers throughout a mandated curriculum change. It might also assist those parties tangentially involved in classroom implementation of curriculum documents, such as administrators, curriculum consultants, educational researchers, and professional development specialists by providing evidence-informed suggestions for curriculum implementation. For example, this study revealed a need for teachers to recognize and explain their epistemic beliefs about physics knowledge, an often-ignored area for most teachers (Huling, 2014; Mulhall & Gunstone, 2008), and consider how these epistemic beliefs inform their concerns. It may be that findings from this study promote changes that support the preparation of teachers to approach and better engage with curriculum change.

Finally, this study offered teacher participants the chance to deeply consider their epistemic beliefs about physics knowledge and how those beliefs informed their interpretation of the curriculum document. “[Epistemic] beliefs are critical to the learning process” (Schommer, 1994b, p. 315). Given that teachers are intimately tied to the learning process, epistemic beliefs should be of importance to any educator. “By helping teachers understand their beliefs, we can develop more reflective teachers who can not only grow professionally but who can also promote awareness and growth in their students” (Jones & Leagon, 2014, p. 843). This study encouraged participating teachers to reflect on and voice their epistemic beliefs about physics knowledge while also offering the opportunity to share their concerns about the 2017 curriculum document. Educational researchers have claimed that physics teachers often work in isolation (e.g., Kelly & Sheppard, 2010; Nehmeh & Kelly, 2018; Tesfaye & White, 2012) and rarely have opportunities to discuss their teaching and subject of instruction with others teaching physics. This study offered participating teachers an opportunity to discuss their beliefs and connect with someone else versed in teaching physics in Saskatchewan, this researcher. Hopefully, this study encouraged participants to further reflect on their epistemic beliefs about physics knowledge and how these beliefs impacted their interpretation (and enaction) of the 2017 Saskatchewan Physics 30 curriculum document.

1.3. Research Questions

Arising from the literature presented in the following chapters, this study explored the connections between Saskatchewan physics teachers' epistemic beliefs about physics knowledge and their concerns regarding the implementation of the 2017 Physics 30 curriculum document. It should be noted that the word 'concerns' was used in this investigation to connect to the existing body of literature about teachers' concerns and does limit the scope of this study. I recognized that teachers also had positive reactions to the 2017 curriculum document. Teachers' concerns were formally analyzed but data was also collected regarding their positive experiences with this document. Ultimately utilizing qualitative data, I investigated the following question:

1. Were there connections between teachers' epistemic beliefs about physics knowledge and their concerns with the 2017 Saskatchewan Physics 30 curriculum document?

To support this question, the following questions were also investigated:

2. What were Saskatchewan Physics 30 teachers' epistemic beliefs about physics knowledge?
3. What were Saskatchewan Physics 30 teachers' concerns about the 2017 Physics 30 curriculum document?

CHAPTER 2: LITERATURE REVIEW

This chapter opens by explaining epistemic beliefs as they were conceived in this study, specifically, epistemic beliefs about physics knowledge. Following a review of literature on epistemic beliefs, science curriculum development is described and situated within both the Canadian and Saskatchewan contexts. The 2017 and 1992 Saskatchewan Physics 30 curriculum documents are briefly compared. Educational change is discussed, and what is meant by teacher concerns in this study is elaborated. Studies investigating concerns as responses to changes in science curricula are analyzed and areas of concern commonly reported in the literature are identified.

2.1. Epistemic Beliefs About Physics Knowledge

Epistemology is a philosophical area concerned with people's characterizations of what constitutes knowledge (Hofer & Pintrich, 1997). Epistemology does not have a single, well-constructed definition (Fives & Beuhl, 2017; Hofer & Pintrich, 1997; Hofer & Sinatra, 2010), but researchers working in the field of epistemology are typically interested in beliefs about the source of, certainty of, and organization of knowledge (Hofer & Bendixen, 2012; Schommer, 1994a). Formulated based on one's epistemology, or philosophy of knowledge (Moshman, 2015), epistemic beliefs describe what one conceives of as knowledge. Epistemic beliefs refer to a person's thoughts about the nature and conceptualization of knowledge (Dolphin & Tillotson, 2015). It is within these constructed belief systems that information is received and interpreted.

Before digging into definitions, I wish further define the scope of this study. First, a reader might wonder why I have not included a discussion on the nature of science. The nature of science describes what I consider to be the epistemology of the subject; focused on defining philosophical considerations of what constitutes science such as the repeatability, social orientation, and changing landscape of science (McComas, 1996; McLelland, 2006), whereas epistemic beliefs research is concerned with individuals' *beliefs* about the characteristics and conceptualizations of knowledge (Siegel, 2014). This study focused on those epistemic beliefs physics teachers held about physics knowledge, how they might depict knowledge in physics, and how they related to these beliefs and thoughts (Dolphin & Tillotson, 2015). This study did not aim to define the epistemology of physics.

2.1.1. Defining Epistemic Beliefs as They Were Conceived in This Study

Research about science teachers' epistemic beliefs has commonly focused on beliefs in relation to teaching, instruction, and learning in science (e.g., Boz & Boz, 2014; Dolphin & Tillotson, 2015; Feucht, 2017; Mansour, 2013; Tsai, 2002). It can be argued that beliefs about learning are external to epistemic beliefs about a subject, but are related, like the connections between epistemology and motivation, conceptual change, and metacognition (Hofer & Bendixen, 2012). In this study, based on works such as Baytelman et al. (2020) and Hofer and Pintrich (1997), it was reasonably expected that epistemic beliefs about physics knowledge could be studied without focusing on beliefs about learning physics knowledge, even though both contribute to one's epistemological worldview[3].

Epistemic beliefs about learning—and those concerning the practice of teaching—are undoubtedly connected to one's epistemological worldview regarding the discipline of physics. However, as discussed in Chapter 1, those questions and conversations that I had with many teachers about the 2017 Physics 30 curriculum document prior to this study were focused on the 'physics' (i.e., the content and knowledge-based outcomes) within the curriculum document.

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[3] An epistemological worldview "consists of a set of beliefs that collectively define one's attitudes about nature and acquisition of knowledge" (Olafson & Schraw, 2010, p. 520).

Given these conversations, and the recommendation from researchers such as Baytelman et al. (2020) and Hofer (2012) to separate learning from epistemic beliefs about a discipline, I focused my work in this study on teachers' epistemic beliefs about physics knowledge and did not intend to investigate teacher practice or beliefs about learning.

For those unfamiliar with the epistemic beliefs research, it may be worth noting that researchers in this area often take great care to define what they mean by epistemic beliefs. This field of research uses many terms to define similar, yet slightly different, ideas. For example, the term *epistemic beliefs* has been used to describe (1) an individual's knowledge and beliefs about knowledge (e.g., Kitchener, 1983; Hofer & Pintrich, 1997) and (2) an individual's beliefs about knowledge (e.g., Murphy et al., 2012). Researchers have also used the term *personal epistemology* as describing an individual's knowledge and beliefs about knowledge (e.g., Hofer, 2012; Pintrich, 2012). To make things more complicated, researchers often interchange these terms (Hofer & Bendixen, 2012; Schommer-Aikins, 2012; Schraw et al., 2017). For example, Walker et al. (2020) when defining the term 'epistemic beliefs', use the definition that Hofer and Pintrich (2002) use to define 'personal epistemologies'; this practice is common in this field of research (and very confusing for the new researcher).

I use the term *epistemic beliefs* in this study but recognize that the terms 'personal epistemology' or 'epistemological beliefs' may, for others, describe beliefs about knowledge. I followed the work researchers such as Bendixen (2012) and Elby et al. (2016) who differentiate epistemic beliefs from epistemological beliefs by describing epistemological beliefs as being focused on epistemological development. Epistemological beliefs would be those unidimensional beliefs described by researchers such as Belenky et al. (1986), Kitchener (1983), and Perry (1970). As highlighted by Feucht (2017), epistemic beliefs are also referred to using the term personal epistemology. However, as Hofer (2012) explains, research using the term personal epistemology frequently includes beliefs about learning in their conceptual frameworks. As aforementioned, epistemic beliefs about learning are considered to be separate from epistemic beliefs about knowing in an academic subject. I asked teachers about their beliefs about their conceptions of physics knowledge; hence, I use the term *epistemic beliefs*. Epistemic beliefs, as they are conceived in this study, reveal an individual's perception of how knowledge is conceptualized. Yet, I recognize that this is how I interpret the difference between these terms and that this may be slightly different for each researcher in this field.

The lack of a single, consistent definition contributes to the murkiness of the field of epistemic beliefs research. Beliefs research, in general, is messy (Pajares, 1992) and to claim one can neatly define these terms—separable from the others—would misconstrue the field. Given this convolution, as suggested by Pintrich (2012), it is important that researchers investigating epistemic beliefs (or personal epistemology or epistemological beliefs) describe how they interpret the term (Schommer-Aikins, 2012). In this dissertation, I have tried to clarify the, often murky, waters of epistemic beliefs in education but am only able to do so from my interpretation.

2.1.2. Defining Beliefs and Their Origins

Jones and Leagon (2014), in an overview of the literature on science teacher beliefs, highlighted the deeply intertwined nature of knowledge and beliefs. Knowledge is based on one's beliefs (Moshman, 2015) and it is very difficult to separate these two constructs. Alexander and Dochy (1995), in exploring how adults described what was meant by knowledge and beliefs, found that most participants (41%) felt knowledge and beliefs were integrated as well as independent. Participants who expressed this conceptualization of beliefs and knowledge suggested that beliefs about a subject influence what you know, but what one has learned also influenced how knowledge was viewed, i.e., one's epistemic beliefs. Due to the intertwined development of epistemic beliefs and knowledge, it is difficult to separate these two entities. A person's view of what constitutes knowledge within a subject is based on both personal beliefs—influenced by many factors—and on those knowledge structures ascribed to a discipline. In this section, I address how I interpreted the term *belief* as well as define those belief orientations within physics as identified in the literature.

The Oxford English Dictionary refers to a 'belief' as an accepted idea or an idea in which a person places their trust ("Belief", 2016). Beliefs are rooted in what we consider knowledge. In this study, epistemic beliefs were considered a theoretical construct that allowed this researcher to conceptualize teachers' knowledge (Southerland et al., 2001). An individual's epistemic beliefs inform their views on knowledge, what counts as knowledge, and in what knowledge they trust. We are a product of our experiences (Dewey, 1916), and it is only through these experiences—and our perceptions—that we can observe physical phenomena and interpret evidence (Barnes et al., 1996; Fives & Beuhl, 2017; Zukav, 1979). Our conceptualizations of knowledge—our epistemic beliefs—are influenced by constructed systems of knowledge and rooted in our experiences, guiding our perception of the world. Epistemic beliefs represent what a person sees as knowledge. Yet, what informs these beliefs?

Educational literature has explored educational experiences as influencing epistemic beliefs about physics knowledge (e.g., Feucht, 2017; Hammer, 1994; Yavuz, 2014). Beliefs about what constitutes knowledge within a discipline are influenced by the presentation of the information that individuals use to construct knowledge. For example, Yavuz (2014) in studying epistemic approaches to solving physics problems found that many undergraduate physics students preferred to use formulae instead of using intuition. In interviews, students attributed this conformation to their professors' focus on using mathematical methods. Students interpreted this focus as indicating that mathematical methods were more trustworthy than intuition when solving physics problems. The epistemic emphasis experienced during schooling, including post-secondary education, informs—at least in part—the development of an individual's epistemic beliefs about physics knowledge.

Formal education is not the only factor affecting an individual's beliefs about the conceptualization of physics knowledge. Experience deeply influences epistemic beliefs about physics knowledge. For example, one student interviewed by Hammer (1994) explained that much of his physics knowledge was guided by common sense, presumably developed through informal experiences. Common sense can be defined as accepted and invisible knowledge (Driver et al., 1994). For some, this presumed way of knowing may not be an accessible method of knowing physics since personal experiences may not align with the way science knowledge is presented in formal situations. In addition, misconceptions based on misinterpreted common sense can contribute to misrepresentation of what constitutes physics knowledge. In this sense, experience and expected common sense may raise a wall between what students perceive to be physics knowledge and how physics is taught. Experiences with physics in both formal and informal settings determine what a person considers to exemplify physics knowledge.

2.1.3. Epistemic Beliefs and Physics Knowledge

In this section, I describe the aspects of epistemic beliefs, physics knowledge, and epistemic beliefs about physics knowledge. As highlighted in Chapter 1 of this thesis, many of the questions I heard and those informal conversations I had about the 2017 curriculum document prior to this study were focused on a change to the content (meaning the knowledge-based outcomes within the document) being taught in Physics 30. Consequently, I began reading about personal epistemologies and epistemic beliefs about physics and came across David Hammer's (1994) article which discussed beliefs about the coherence and content of physics knowledge. It was also assumed, as supported by Hofer (2012), that epistemic beliefs were domain-specific—meaning that teachers' epistemic beliefs about physics may differ from their beliefs about other academic subjects and their epistemic beliefs in general. Given that teachers' concerns, anecdotally, were focused on physics content/knowledge in the 2017 Physics 30 document, and assuming that epistemic beliefs were specific to an academic domain, I wondered whether teachers' epistemic beliefs about physics knowledge connected to their concerns.

2.1.3.1. Physics Knowledge. Academic domains, such as physics, consist of a well-structured and unified paradigm utilizing an accepted body of knowledge (Muis, et al., 2006; Wheelahan, 2010). These paradigms define what counts as knowledge for each academic domain. Some aspects of a paradigm may cross-pollinate specific domains, such as the way one can consider biology, chemistry, and physics to all utilize a knowledge structure common to science; a knowledge structure based on testable explanations and evidence-based predictions. Even so, consider the structure and creation of knowledge in physics versus biology as portrayed in a typical Western-Canadian high school. Physics courses often rely heavily on the explanation of patterns utilizing equation manipulation to understand mathematical relationships to support findings, whereas biology courses tend to use interpretation of chemical reactions and sense-based data and evidence, using mathematics in the form of geometry and statistics. These subjects are both sciences, but they are considered distinct academic domains. Barnes et al. (1996) claim the separation of the sciences has been devised by convention. Is physics different from biology? They are both sciences, with knowledge derived from data interpretation, evidence, and theory. Yet, I contend that knowing in these two areas is different since the evidence is often collected in different ways and interpreted using different knowledge structures. To successfully navigate a discipline, one must be versed in those knowledge structures specifically utilized within that discipline since academic disciplines—such as physics—operate with classified bodies[4] of knowledge (Wheelahan, 2010).

2.1.3.2. A Note on Dichotomies and Continua. Before discussing the areas of epistemic beliefs about physics knowledge, I would like to address what I perceive to be a common misrepresentation in the literature about epistemic beliefs research. This misrepresentation is the presentation of epistemic beliefs as binary; that is, researchers representing epistemic beliefs as either one belief or another. Frequently, researchers use two terms, labelled as naïve or sophisticated epistemic beliefs. For example, Schommer (1990) described epistemic beliefs about the certainty of knowledge as indicating that an individual believed that knowledge was absolute and unlikely to change (the naïve view) or that knowledge was tentative and subject to change (the sophisticated view). This practice of dichotomizing beliefs into binary representation continues with more recent research; Chinn and Barzilai (2017) discuss epistemic beliefs about the structure of knowledge as represented by either believing that knowledge is simple (i.e., information is isolated) or believing that knowledge is complex (i.e., information is connected to create a coherent knowledge system). I sought to represent epistemic beliefs using a more nuanced conceptualization, as deemed necessary by Sinatra (2016).

Sinatra (2016) and Murphy and Alexander (2016) call on researchers (especially early researchers in epistemic beliefs) to move from binary representations of epistemic beliefs to

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[4] Wheelahan (2010) discusses the classification of knowledge as defining *what* can be expressed by a discipline. A classified body of knowledge, in this work, is one where the knowledge within this body can be distinguished from and related to the knowledge of other bodies (i.e., disciplines). Defining physics as a classified body of knowledge allows us to define what knowledge can be described by physics and what knowledge cannot.

representations that better represent the nuanced nature of epistemic beliefs. Yet, no method of representation was identified by either Sinatra or Murphy and Alexander. In response to this call, and synthesizing the work of Hammer (1994) and Tsai (2006), I propose viewing epistemic beliefs as existing along continua and describe how continua are applied to my study in *2.1.4. Conceptual Framework for Analyzing Epistemic Beliefs about Physics Knowledge*. For now, I wanted to clarify for the reader that, while I discuss two extremes in each area of belief, I conceive of epistemic beliefs about physics knowledge as being represented as lying between each of these commonly used extremes.

2.1.3.3. Epistemic Beliefs about Physics Knowledge. Educational researchers (e.g., Fives & Beuhl, 2017; Hofer & Pintrich, 1997; Schommer-Aikins, 2012) have debated whether epistemic beliefs are domain-specific (i.e., subject-specific) or domain-independent (i.e., common across all subjects). Epistemic beliefs research—particularly at its origins—primarily considered epistemic beliefs to be unidimensional and domain general (e.g., Belenky et al., 1986; Kitchener, 1983; Perry, 1970). However, more recently—and specifically in mathematics and science education—discipline-specific beliefs have been of interest (Hofer, 2012). Studies focusing on epistemic beliefs about science often concern themselves with areas common to epistemic belief research focused on other disciplines, such as epistemic beliefs about the source, certainty, and organization of knowledge (see Feucht, 2017; Schommer, 1994a; Schommer-Aikins, 2012). Those studies focused on epistemic beliefs about physical science knowledge also include the addition of content-specific knowledge, such as the use of mathematics in the discipline (i.e., Adams et al., 2006; Halloun, 1997; Hammer, 1994; Redish et al., 1998). This research focused on those epistemic beliefs about physics knowledge, ergo, epistemic beliefs were considered domain specific.

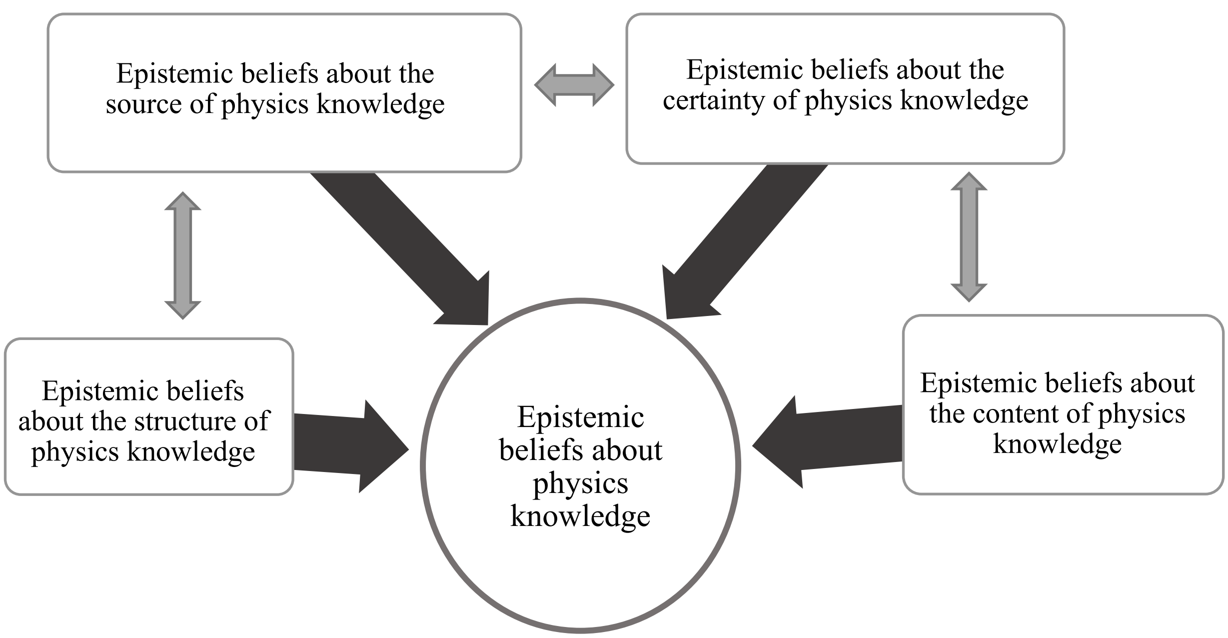
As physics knowledge is located within its own academic discipline, its knowledge has distinct characterizations. After reviewing the literature, four areas were identified as contributing to one's epistemic beliefs about physics knowledge: these included epistemic beliefs about the (a) source, (b) content, (c) certainty, and (d) structure of physics knowledge. These four areas make up a system of epistemic beliefs, similar to the model proposed by Hofer and Pintrich (1997) that is still used by studies today (e.g., Chevrier et al., 2019). Hofer and Pintrich based their work on that of Marlene Schommer (1990) but removed the aspects of Schommer's model focused on learning and ability. Hofer and Pintrich described epistemic beliefs as consisting of loosely connected dimensions that each describe one aspect of knowledge. For example, a person's epistemic beliefs about the certainty of knowledge can be represented as perceiving knowledge as absolute and unchanging, as tentative and evolving, or as somewhere between these two extremes. Together, these areas can describe an individual's epistemic beliefs about physics knowledge—how they conceptualize knowledge within the discipline of physics.

The framework for epistemic beliefs about physics knowledge proposed for this study reflected a multidimensional view of epistemic beliefs specific to the domain of physics knowledge. This multidimensional approach reflects those frameworks often used to describe individual's epistemic beliefs, or personal epistemologies (see Feucht, 2017; Fives & Beuhl, 2017; Hofer, 2000; Hofer & Pintrich, 1997). The dimensions of this system were loosely connected but, as in systems described by Schommer-Aikins (2012), these dimensions are also more or less independent. For example, one could not predict a teacher's epistemic beliefs about the content of physics knowledge by knowing their epistemic beliefs about the certainty of physics knowledge. A representation of these four areas as they were considered to contribute to the construction of one's system of epistemic beliefs about physics knowledge is shown in Figure 1.

2.1.3.3.1. Epistemic Beliefs about the Structure of Physics Knowledge. Epistemic beliefs about the structure of physics knowledge portray whether a person conceived of physics knowledge as consisting of individual, isolated pieces of information, as a coherent system of ideas, or as some combination of these two extremes. These two extremes have been commonly investigated within those studies on epistemic beliefs about physics or science (e.g., Adams et al., 2006; Buehl & Fives, 2016; Chevrier et al., 2019; Elby et al., 1997; Halloun & Hestenes, 1998; Hammer, 1994; Muis & Geirus, 2014; Redish et al., 1998). Both Schommer's (1990, 1994a) and Hofer and Pintrich's (1997) models included a dimension (or area of personal theory) focused on an individual's beliefs about the coherence, or complexity, of a subject. An

Figure 1

Depicting the Epistemic Beliefs about Physics Knowledge



individual's epistemic beliefs about the structure of physics knowledge was one aspect contributing to their epistemic beliefs about physics knowledge.

According to Mäntäyla and Nousiainen (2014), new concepts or ideas in physics are connected to previous concepts when they are formed. This view was supported by Barnes et al. (1996) who claimed that theory and observation cannot be separated; one could not observe something new in science without referencing already known theory. This would imply that physics, as a discipline, exhibits a coherent and connected set of ideas, a sentiment expressed by physicists (Halloun, 1997; Halloun & Hestenes, 1998).

Yet, in study conducted by Hammer (1994), students often expressed one of two sentiments about the structure of physics knowledge: either physics knowledge consisted of pieces of isolated information or—as mentioned above—physics knowledge existed as a single, coherent system. These depictions of the structure of physics knowledge were corroborated by the findings of a study with high school and university physics students where students in both settings frequently indicated that "physics consists of a loose collection of directly perceived facts," (Halloun & Hestenes, 1998, p. 559).

As physics teachers lay between being experts (i.e., physicists and scholars of science)—who have been described as viewing physics knowledge as a coherent system of ideas (Halloun & Hestenes, 1998)—and students of physics—often viewing physics knowledge as isolated pieces of information—their epistemic beliefs about the structure of physics might be described between these two extreme views. Following the literature, I included epistemic beliefs about the structure of physics knowledge as one element of an individual's epistemic beliefs about physics knowledge.

2.1.3.3.2. Epistemic Beliefs about the Source of Knowledge in Physics. The source of physics knowledge identifies whether an individual perceives physics knowledge as being metaphysical (where knowledge is discovered), physical (where knowledge is invented), or a combination of both. The metaphysically-oriented physicist perceives an authority-determined model to which knowledge must be matched (Davis, 2004), a physics of pre-determined ideas and structures discovered by physicists. Johannes Kepler, like many metaphysical physicists of his time, held the belief that "we are bound to the world God made and are not free to create one of our own" (Jongsma, 2001, p. 166). Leibniz, Galileo, and Descartes—all of whom were major contributors to the discipline of physics—shared this epistemic belief that physics knowledge was to be discovered; that it already existed, irrespective of human existence. These scientists and philosophers believed they were exposing a pre-existing set of principles independent of human influence; physics pre-existed the knower and humanity discovered these principles.

On the other hand, physics knowledge might also be described as physical—rooted in experience and designed by humans (Burbules & Linn, 1991; Sin, 2014; Zukav, 1979). Those subscribing to this epistemic belief about the source of physics knowledge describe physics knowledge as derived from humans constructing knowledge based on their interactions with the physical world. From this standpoint, physics knowledge would be shared (and created) within a community not held (or discovered) by one individual (Sloman & Fernbach, 2017). Physicists such as Neils Bohr, Thomas Kuhn, and Lee Smolin have each claimed that physics knowledge was developed through human influence and by a scientific community (Gregory, 1988; Kuhn, 1996; Smolin, 2006). Those believing such argued that the discipline of physics was invented based on our interactions with (and experiences of) the world; that is, human influence controls how we describe our world.

Just as physicists such as Bohr, Descartes, Kepler, and Smolin have philosophized about the source of physics knowledge, the epistemic belief literature has also considered epistemic beliefs about the source of knowledge. Studies have investigated epistemic beliefs about physics and/or science knowledge by making a distinction between physics knowledge as invented by humanity or discovered from an external system (e.g., Adams et al., 2006; Elby et al., 1997; Muis & Geirus, 2014; Redish et al., 1998; Tobin & McRobbie, 1997). Given the claims of physicists such as Bohr and Kepler, and the literature investigating epistemic beliefs, I conceptualized epistemic beliefs about the source of physics knowledge to describe the extent to which one perceives physics knowledge as discovered from an external reality, as invented by humans interacting with the world, or as some combination of these two sources.

2.1.3.3.3. Epistemic Beliefs about the Certainty of Physics Knowledge. This area of epistemic beliefs about physics knowledge described whether an individual perceived physics knowledge as being absolute and unchanging, as being tentative and subject to change, or as some combination of the two. Literature has explained that non-scientists tend to conceive of traditional science as focused on a product and correct explanations (Musser, 2019; Roberts, 1982), but this requires constant and unchanging information to produce eternally correct explanations. This begs the question: “Can knowledge in physics change?”

Consider the following example, in 2012 evidence for a theorized subatomic particle (the Higgs Boson) was presented by experimental physicists. Yet, this experiment also produced evidence for a new particle to exist—the graviton. Previously theorized, the confirmed existence of the graviton forced physicists to reconsider humanity’s collective understanding of physics. This alteration of physics knowledge—based on the metaphysical search for a theorized particle—produced new knowledge informing physicists’ collective understanding of our universe. Ideas such as multiple universes moved from mere musings to potential realities as existing science knowledge was reexamined. In this study, individuals expressed their epistemic beliefs about the certainty of physics knowledge as conceiving of physics knowledge as absolute and unchanging, as tentative and subject to change, or as some combination of the two.

Researchers who have investigated peoples' epistemic beliefs about physical science commonly asked participants whether they saw scientific knowledge as tentative and refutable or as absolute and unchanging (e.g., Elby et al., 1997; Chevrier et al., 2019; Halloun, 1997; Halloun & Hestenes, 1998; Muis & Geirus, 2014; Tobin & McRobbie, 1997; Tsai, 2006). Irrespective of whether physics knowledge is absolute, tentative, or something in between, science teachers often teach courses that imply an unchanging and orderly knowledge structure (Burbules & Linn, 1991; Sin, 2014). In a study conducted with Taiwanese science teachers, Tsai (2006) found mixed responses when teachers were asked about whether science knowledge was tentative. As one example, a participant in Tsai's study agreed that knowledge in science could change, but she also explained science as operating with what she called fundamental knowledge, and, according to her, it was unlikely this fundamental knowledge would change. However, arguably, gravity is fundamental knowledge to the field of physics and—as outlined above—our understanding of gravity has changed. Whether scientific knowledge is tentative or constant was not a focus of this study, but an individuals' epistemic beliefs about the certainty of physics were an element of their epistemic beliefs about physics knowledge.

2.1.3.3.4. Epistemic Beliefs about the Content of Physics Knowledge. The discipline of physics blends qualitative explanation with mathematics, but—as is common in the literature—this study considered epistemic beliefs about the content of physics knowledge as oriented more toward algorithmic mathematics and formulae or more toward conceptual, qualitative understandings of physics. The literature frequently presents physics knowledge experienced in high school and early university courses as focused on either a mathematical understanding (emphasizing the use of formulae) or a conceptual understanding (qualitative explanations or solutions based on an understanding of physical principles and/or intuition) (Muis, 2008; Mulhall & Gunstone, 2008; Hammer, 1994; Pospiech, 2019; Sherin, 2001; Shtulman, 2015; Sin, 2014; Wei & Chen, 2019; Yavuz, 2014). It has even been claimed that physics theory exists between mathematical theory and reality (Krey, 2019).

Hammer (1994), in his research with first year physics students, claimed that content in physics was often either described as formula centred—stemming from facts, formulae, and procedures—or as conceptual—based on intuition and logic. To Hammer, solving a problem with conceptual physics meant qualitatively employing the principles of physics involved in the problem and developing a solution based on a sound understanding of physical principles without necessarily requiring calculation. On the other hand, using formula-based physics meant solving problems by applying and manipulating the appropriate mathematical formulae. As acknowledged by Yavuz (2014), this binary encapsulation of epistemic beliefs about the content of physics knowledge places formulae on one end of knowing and conceptual physics—employing intuition and qualitative explanations based on physical understandings—at the other.

Ignoring the physical properties and relationships inherent in the mathematics used when teaching physics can make conceptual physics and mathematics appear to be separate entities when they are not (Redish, 2005; Redish & Kuo, 2015; Sherin, 2001). This may change as students progress in their schooling. For example, Sherin (2001) found that some upper year, post-secondary physics students applied their understanding of conceptual physics and mathematical relationships to the creation of formulae to solve a problem. Despite that claim, this was not considered to be common in students' high school physics careers (Redish, 2005). Mathematics and conceptual physics may not be separate entities but they are often presented as the two different types of content when considering epistemic beliefs about physics knowledge.

2.1.3.4. Summarizing the Epistemic Beliefs about Physics Knowledge. Epistemic beliefs about physics knowledge, in this study, entailed those beliefs that a person held about the source, content, certainty, and structure of physics knowledge. This section provided an overview of the four areas of epistemic beliefs about physics knowledge. Table 2 is a summary of these four areas and their dichotomies.

2.1.4. Conceptual Framework for Analyzing Epistemic Beliefs about Physics Knowledge

Employing the four areas of epistemic beliefs about physics knowledge (see Table 2), this study introduced a literature-based conceptual framework to help organize my response to the

Table 2

Summary of the Four Areas of Epistemic Beliefs about Physics Knowledge

1. Epistemic beliefs about the structure of physics knowledge were represented as lying between the two extremes:
    - Physics knowledge as a collection of isolated ideas, or
    - Physics knowledge as a coherent system of connected ideas.

2. Epistemic beliefs about the source of physics were represented as lying between the two extremes:
    - Physics knowledge as discovered from an external reality, or
    - Physics knowledge as invented based on knowers' interactions with reality.

3. Epistemic beliefs about the certainty of physics knowledge were represented as lying between the two extremes:
    - Physics knowledge as absolute and unchanging, or
    - Physics knowledge as tentative and subject to change.

4. Epistemic beliefs about the content of physics knowledge were represented as lying between the two extremes:
    - Physics knowledge as mathematics oriented in formulae, or
    - Physics knowledge as concept oriented and qualitatively explainable.

question, “What were Saskatchewan Physics 30 teachers’ epistemic beliefs about physics knowledge?”

Throughout this study, epistemic beliefs about physics knowledge were considered to fall along continua ranging between the two defined extremes for each area of epistemic beliefs about physics knowledge. These four continua were:

(1) An individual’s beliefs about the structure of physics knowledge were described as lying between (a) a collection of isolated ideas and (b) a coherent system of connected ideas;

(2) An individual’s beliefs about the source of physics knowledge were described as lying between (a) invented by humans and (b) discovered from an external reality;

(3) An individual’s beliefs about the certainty of physics knowledge were described as lying between (a) absolute and unchanging and (b) tentative and subject to change; and,

(4) An individual’s beliefs about the content of physics knowledge were described as lying between (a) mathematics oriented in formulae and (b) concept oriented and qualitatively explainable.

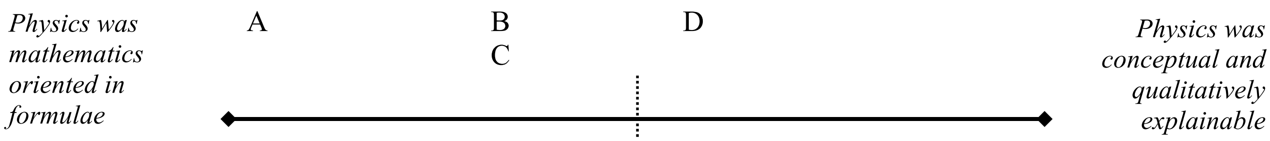
A continuum can be considered a series of continuous elements passing into each other (“Continuum”, 2016). In this study, an individual’s epistemic beliefs about physics knowledge were considered to align with either extreme or anywhere between the two. Given this continuum conceptualization, teachers’ epistemic beliefs about physics knowledge were representable as points along a continuum ranging between two defined extremes of each area of epistemic beliefs. It should be recognized that each existing ‘belief placement’ between these two extremes was indistinguishable from those immediately surrounding it.

To illustrate the idea of a continuum that represents an area of epistemic beliefs about physics knowledge, I will further explicate the fourth dimension of epistemic beliefs about physics knowledge—epistemic beliefs about the content of physics knowledge. Yavuz (2014), in his study investigating epistemic trust with first-year physics students in Turkey, acknowledged the dichotomy describing beliefs about the content of physics knowledge as mathematics oriented or qualitatively explainable as putting "physics formulae at one end and concepts at the other end" (Yavuz, 2014, p. 633). This dichotomy has predominantly been presented as a binary, which ignores the nuanced nature of epistemic beliefs (Murphy & Alexander, 2016; Sinatra, 2016). In this study, I seek to contribute to the literature revising this conception of binary beliefs and suggest that physics knowledge can be conceptualized as consisting of formulae, qualitative descriptions, or as any combination of both.

Physics is rooted in mathematics (Redish & Kuo, 2015), and conceptual, or qualitative, physics cannot be completely separated from the formula-based language of this discipline. Even so, as shown by Hammer (1994), Muis (2008), and Yavuz (2014), physics content has been typically viewed as either a formula-centred or a qualitative and conceptual subject. I do not agree that mathematics and qualitative physics can be easily separated—as Adams et al. (2006), Hammer (1994), Yavuz (2014) and others studying this topic have implied—hence, I considered teachers' epistemic beliefs about the content of physics as being represented at a point along a continuum ranging between the beliefs that physics knowledge was mathematics oriented and formulae-based and the belief that physics knowledge was conceptual and qualitative. I propose a continuum framework with physics knowledge as mathematics oriented at one extreme and physics knowledge as concept-oriented, or qualitative, on the other extreme. This continuum is represented in Figure 2.

Figure 2

Visualizing a Continuum of Epistemic Beliefs about Physics Knowledge



As shown in Figure 2, epistemic beliefs about the content of physics knowledge were considered to exist along a continuum with the mathematics-oriented position of physics knowledge—physics knowledge was exclusively formula-based—at one extreme and the qualitatively oriented position of physics knowledge—physics knowledge was exclusively conceptual—at the other. In the middle of the continuum, shown by the dashed vertical line in Figure 2, one would find participants describing physics knowledge as equally represented by formulae and conceptual/qualitative understanding. The letter 'A' on Figure 2 shows the placement of an imaginary participant that has been interpreted as strongly communicating the epistemic belief that the content of physics knowledge was based in mathematics. The letters 'B' and 'C' on Figure 2 show the placement of two imaginary participants that have been interpreted as favouring mathematically oriented physics knowledge but still believing that physics knowledge was somewhat conceptual. As a final example, a fourth imaginary participant, represented by the letter 'D' on Figure 2, is slightly to the right of the neutral position indicating that they agreed with both physics content being conceptual and formulae-based but that they indicated a stronger agreement with physics content as conceptual and qualitatively explained.

Based on this continuum representing epistemic beliefs about the content of physics knowledge, and considering the other three areas of epistemic beliefs about physics knowledge to be similarly represented, epistemic beliefs about knowing in physics were considered to lie along each of four continua, henceforth referred to as the *continua of epistemic beliefs about physics knowledge*. Table 3 shows a summary of the four continua contributing to the description of one's epistemic beliefs of physics. Within this collection of four continua, each continuum was defined with their describing dichotomies at the extreme. However, in interpreting teachers' epistemic beliefs about physics knowledge, it was recognized that each of the four areas of epistemic beliefs about physics knowledge may range between one extreme and the other, with the middle of the continuum representing a neutral stance.

2.1.5. Incompatibility of Epistemic Beliefs

Epistemic beliefs, and their interactions, have been described in the literature in varying ways. For example, Louca et al. (2004) consider epistemic beliefs to consist of independent "grains" of belief, accessed when interpreting transmitted or received knowledge. Hofer &

Table 3

Summary of Extreme Views in Each of the Four Areas of Epistemic Beliefs about Physics Knowledge

Belief Area	Extreme View A	Extreme View B
The structure of physics knowledge	Physics knowledge as a collection of isolated ideas	Physics knowledge as a coherent system of connected ideas
The source of physics knowledge	Physics knowledge as discovered from an external reality	Physics knowledge as invented based on knowers' interactions with reality
The certainty of physics knowledge	Physics knowledge as absolute and unchanging	Physics knowledge as tentative and subject to change
The content of physics knowledge	Physics knowledge as mathematics oriented in formulae	Physics knowledge as concept oriented and qualitatively explainable

Pintrich (1997) describe epistemic beliefs as interdependent beliefs within a continuum of development accessed through theorizing with epistemic beliefs. Domert et al. (2017) offer a third explanation claiming that one's epistemology is a mindset derived from perceptions of learning and knowledge accessed when an individual interacts with knowledge in a learning situation. I contend that epistemic beliefs may be guided by discipline specific views about knowledge as well as personal and societal understandings of knowledge. Individuals consider their knowledge and what they believe about physics knowledge within these constructed belief systems. Hence, I agree with those educational researchers, including Fives and Buehl (2012), Schommer-Aikins (2012), and Wallace & Priestley (2017), claiming that epistemic beliefs operate as a filter through which we see the world.

Those versed in the physics of colour and light will recognize the effects of subtractive mixing when viewing the world through a filter. When holding a coloured filter in front of your eyes, you interpret incoming wavelengths with a different understanding than without the filter. For example, if you held a red filter in front of your eyes, you would be able to recognize the colour of both red and white objects since both produce wavelengths translatable by the red filter. Even objects which are orange or purple in colour may be recognized since they reflect red wavelengths of light; however, they will not appear as the same colour as without the filter since this information (a.k.a., the colour wavelength) is similar to, but not the same as, those which reflect ideal red wavelengths. Therefore, one must guess at the colour of the object based on the information they receive through the filter. Those objects which do not contain red pigment appear to be black or very dark in colour. The filter is unable to translate the information being received and cannot pass this information to the eye for interpretation in any effective matter.

When reviewing a revised curriculum, I contend that teachers interpret the document through the filter created by their epistemic beliefs. Similar to the red filter misinterpreting the colour green as black, a person encountering information that is not easily translated through their epistemic beliefs filter might have difficulty interpreting that information as was intended by those mandating the curriculum. Pekrun et al. (2017) and Muis et al. (2018) found that students reading documents with epistemic orientations differing from their epistemic beliefs showed negative epistemic emotions including frustration and confusion. Similarly, interpreting a curriculum document with an epistemic orientation that is inconsistent with a teacher's epistemic filter might be a frustrating experience, bringing forward concerns about implementing this curriculum. On the other hand, if a teacher's epistemic beliefs align with the intended curriculum document, it could be that their concerns are less focused on the implementation of this curriculum and moving onto optimizing their use of this curriculum.

Epistemic beliefs about physics knowledge are contextually influenced (Tsai, 2002; Muis & Geirus, 2014; Redish & Kuo, 2015; Hammer, 1994). The contextual nature of one's epistemic beliefs about physics knowledge implies the presence of potentially conflicting understandings of this academic domain. For example, a physics teacher may believe that physics knowledge is discovered, unlikely to change, existing in a coherent system and best illustrated using mathematics. Another physics teacher may believe that physics knowledge is discovered, unlikely to change, made of isolated pieces of information, and conceptual. These two teachers hold some common epistemic beliefs (e.g., physics knowledge is unlikely to change and discovered), but their disagreement on the structure and content of physics knowledge may cause misunderstanding and misinterpretation should they ever discuss how they approach teaching the discipline of physics. Perception and beliefs influence the interpretation of scientific knowledge;

individual people may read ‘the same experience’ in different ways (Barnes et al., 1996). Just as there may be alternative conceptions of physics knowledge between the two physics teachers, there may also be a difference in interpretation when these teachers read a physics curriculum document, despite both teachers interacting with the same physical document. On the basis of this reasoning, I propose that—due to interpretation through personalized systems of epistemic beliefs about physics knowledge—teacher beliefs may cause very different reactions to, and interpretations of, curriculum documents.

2.1.5. Summary of Epistemic Beliefs Literature Review

Epistemic beliefs, for this study, have been defined as those beliefs describing how an individual conceptualizes knowledge, specifically physics knowledge. I considered epistemic beliefs as domain-dependent and focused on those epistemic beliefs about physics knowledge. This study explored teachers’ epistemic beliefs specific to physics knowledge as opposed to epistemic beliefs about the teaching and learning of physics. I did not set out to define an epistemology of physics, rather, I intended to explore individuals’ epistemic beliefs about physics knowledge. There are some shared conceptions of physics knowledge across the discipline of physics (e.g., those described by the nature of science and nature of physics), but each teacher was considered to also hold an individually-constructed perspective about their conceptualization of physics knowledge. It should be noted that this study uses the term ‘epistemic beliefs’ to refer what other researchers might label as ‘personal epistemology’ or ‘epistemological beliefs.’

By applying literature and previously conceived conceptual frameworks for interpreting epistemic beliefs, this study introduced the system of epistemic beliefs about physics knowledge (Figure 1). This system defined teachers’ epistemic beliefs about physics knowledge as being represented in four areas: epistemic beliefs about the structure, source, certainty, and content of physics knowledge. An individual's epistemic beliefs about the structure of physics knowledge reflect whether they consider physics knowledge as consisting of either individual, isolated pieces of information, as a coherent system of ideas, or as a combination of the two. An individual's epistemic beliefs about the source of physics knowledge could be represented as existing between two extremes; believing that physics knowledge is invented by humans or physics knowledge is discovered from an external reality. An individual's epistemic beliefs about the certainty of physics knowledge indicate to what degree an individual perceives physics knowledge as tentative and subject to change or as absolute and unchanging. Finally, an individual's epistemic beliefs about the content of physics knowledge indicate whether they consider physics knowledge as being understood through mathematics, through conceptual/qualitative explanations, or through a combination of both.

To further explain this framework, section *2.1.4. Conceptual Framework for Analyzing Epistemic Beliefs about Physics Knowledge* described the four continua through which teachers' epistemic beliefs about the structure, source, certainty, and content of physics knowledge were interpreted in this study. Designed to represent teachers' positions along a continuum of each of the four areas of beliefs, ranging from one extreme view to another, these continua allowed me—the researcher—to visualize, compare, and summarize teachers' epistemic beliefs about physics knowledge in each area. These continua were limited to representation and not able to provide exact measurements but, instead, reflected my interpretations of teachers' beliefs relative to each extreme.

A teacher's epistemic beliefs about physics knowledge influence their interpretation of this curriculum document and this interpretation raises potential for incongruity (or congruity) between those epistemic orientations inherent within a curriculum document and the epistemic beliefs of a teacher interpreting the document. If this (in)congruity of epistemic beliefs causes epistemic emotions, as has been shown in research with students, then it may be that teachers' epistemic beliefs about physics knowledge inform their concerns (i.e., negative epistemic emotions) regarding the 2017 Saskatchewan Physics 30 curriculum document. So, as one aspect of this study, teachers' epistemic beliefs about physics knowledge were investigated through asking the question, "What were Saskatchewan Physics 30 teachers' epistemic beliefs about physics knowledge?" Answers to this question were interpreted using the self-designed conceptual framework for teachers' epistemic beliefs about physics knowledge.

2.2. The Context of Developing the 2017 Saskatchewan Physics Curriculum

Between 2005 and 2017, Saskatchewan made significant changes to their K – 12 science curriculum documents to align Saskatchewan's science curriculum with the Pan Canadian Framework as defined by the Council of Ministers of Education, Canada (CMEC, 1997). This process of renewing the Saskatchewan science curriculum documents concluded in fall 2016 with the release of the Biology 30, Physics 30, and Chemistry 30 curriculum documents (which were revised and re-released in 2017).

This study focused on the curriculum-as-planned (Aoki, 2005), or what is often called the *intended curriculum*. The Science Council of Canada (1984) defined the intended curriculum as "that [which is] prescribed by ministries of education" (p. 4). For this study, the intended curriculum focused on those curriculum documents produced and prescribed by the Saskatchewan Ministry of Education, specifically the Physics 30 (grade 12 physics) curriculum document.

Educational (and curriculum) reform is about more than deploying new documents; it means changing the way that curriculum is viewed, impacting the culture of schools and the communities in which they reside (Fullan, 2016). As an example, the group who wrote the 2017 Saskatchewan Physics 30 curriculum aimed to produce a document with a stronger focus on modern physics by including relevant and (more) recent discoveries in physics. A unit on modern physics was included in the 2017 Saskatchewan Physics 30 curriculum document along with indicators referring to more current research (Saskatchewan Ministry of Education, 2017). This unit consists of two overarching outcomes focused on nuclear physics, quantum mechanics and relativity. These outcomes—and their suggested indicators—highlight the representation of physics knowledge as tentative and downplay the need for complex mathematics in teaching these ideas.

Outcomes in the 2017 Saskatchewan Physics 30 curriculum document differ epistemologically from the 1992 Physics 30 curriculum document. Whether intentional or not, many of the outcomes in the 1992 Physics 30 curriculum document communicated physics knowledge as being absolute and mathematics-oriented. The 2017 curriculum document implied that physics was tentative by including content that resulted as shifts in our understanding of physics as a society (i.e., after Einstein's work, the Manhattan project, etc.). Additionally, the inclusion of very few mathematics-based indicators implied that physics knowledge was (at least in some part) conceptual. It is possible that this change created an incompatibility between the epistemic beliefs of teachers and the way physics knowledge was portrayed within this document. I considered whether teacher concerns might be influenced by this change in epistemic orientation, thereby influencing teachers' reception of this curriculum. In this study, the idea of curriculum reform referred to the change of the curriculum-as-planned, specifically the change of Saskatchewan's Physics 30 curriculum documents from 1992 to 2017.

2.2.1. Science Curriculum in Canada

In 1984, the Science Council of Canada (SCC) released *Report 36 - Science for Every Student*, with the intent of calling all Canadians to recognize the importance of an understanding of science and technology. The terms of what exactly all science students should be learning remained vague in this document beyond the acknowledgement that quality, authentic, Canadian-focused science education should be made available to all students. The writing and production of Canadian Science curricula was—and remains—a provincial responsibility (Milford & Tippett, 2019). The mid-1980's release of *Science for Every Student* brought about the beginning of the search for commonality in science education across Canada.

The difference in provincial curricula was not a significant concern until the rise of international science studies within the 1990s (Fazio et al., 2007). The implementation of the Trends in International Mathematics and Science (TIMSS) testing in 1995, highlighted a need to improve science education in Canada (Fazio et al., 2007). It was also during this time that the *Victorian Declaration* was released which called for harmony between provincial science curricula (CMEC, 1993). These impacting factors, along with a lack of scientific literacy in the general public (McKenzie, 1994) and the guiding advice of *Science for Every Student* (released in 1984) led to the creation of the *Common Framework of Science Learning Outcomes: Pan-Canadian Protocol for Collaboration on School Curriculum, K – 12* (also referred to as the *Pan Canadian Framework* or *Common Framework*) released by the CMEC in 1997 as explained by Fazio et al. (2007).

After the release of the Pan Canadian Framework, provincial governing bodies determined curricular outcomes based on the common goal of improving scientific literacy. Milford et al. (2010) criticize that a formal definition of scientific literacy was not given within the Pan Canadian Framework; yet, the CMEC (1997) heavily stressed that all students acquire scientific literacy. Applying a broad definition, scientific literacy can be viewed as “what the public should know about science in order to live more effectively with respect to the natural world,” (DeBoer, 2000, p. 594). The Pan Canadian Framework outlines four categories of scientific literacy: (a) science, technology, society, and environment (STSE), (b) skills, (c) knowledge, and (d) attitudes (CMEC, 1997, p. iv). According to this framework, possessing an understanding of all four areas, as they relate to effectively living within society, evidences an acceptable level of scientific literacy.

The Pan Canadian Framework gave more structure to the calls of *Science for Every Student* and provided a loose structure from which to build a science curriculum while still allowing each province to develop its curriculum documents. This explains some of the commonalities across provincial curricula such as the study of *rocks and minerals* in Grade 4 and *chemical reactions* in Grade 10 science (Milford & Tippett, 2019). Although Milford et al. (2010) criticized the Pan Canadian Framework as being out of date, many of Canada’s science curricula at the time of writing this dissertation were still designed based on the Pan Canadian Framework as of 2019 (Tippett et al., 2019). Specifically, science curricula in the Canadian territories and prairie provinces (Alberta, Saskatchewan, Manitoba, Nunavut, and Northwest Territories) had designed their goals, pillars, or outcomes based on the Pan Canadian Framework (Tippet et al., 2019).

Undeniably, the Pan Canadian Framework's broad requirement of scientific literacy was a requirement many (if not all) science teachers could support (De Boer, 2000; Milford et. al, 2010). After all, who would oppose having Canadian science students become scientifically literate? However, as highlighted by Tippet et al. (2019), the Pan Canadian Framework description of scientific literacy was over 20 years old and these authors "behoove[d] stakeholders to consider more recent perspectives in a refresh of the [Pan Canadian Framework]," (p. 325). Many science curriculum documents, particularly in Western Canada, remained rooted in the 20-year old definitions of the Pan Canadian Framework despite the field of science education having moved forward between 1997 and 2019.

A major aim of any science curriculum document based on the Pan Canadian Framework was to develop scientific literacy, yet, I wondered whether this definition would be the same, or even similar, for individual teachers? As an individual's reality is rooted in perception (Seth, 2019), I suspected not. Sammel and Zandvliet (2003) highlighted the potential for varying interpretations of the Pan Canadian Framework in STSE. In their argument, both Ontario and British Columbia developed their science curriculum using the Pan Canadian Framework and both undertook radically different approaches to STSE education. All curriculum documents are written from a particular political perspective (Pinar et al., 1995). Socio-cultural, economic, and political beliefs all likely influenced the interpretation of the Pan Canadian Framework in both Ontario and British Columbia and, thus, two different approaches emerged. Given that those reading the Pan Canadian framework likely had different systems of epistemic beliefs about science, it was unsurprising that two provinces created two diverse curricula based on the same framework. Similarly, teachers might also likely produce varying interpretations of curriculum documents, dependent on their beliefs. This personal interpretation may have resulted in epistemic incongruities, which, in turn, potentially informed teacher concerns. This science may be for every student, but is the curriculum for every teacher?

2.2.2. Writing Curricula in Saskatchewan

In the mid-1940s, Henry Janzen was appointed Saskatchewan's Director of Curriculum. As Janzen dug into issues surrounding Saskatchewan Education, he unearthed widespread teacher discontent with rigid systems and testing (Lyons, 2006). Janzen felt this was primarily due to the top-down approach of curriculum writing being used; curricular documents were entirely written by university experts and controlled by the Department of Education. To deal with this issue, Janzen requested the creation of a curriculum planning advisory committee with members from various stakeholders including the Saskatchewan Wheat Pool, the Chamber of Commerce, the Farmer's Union, the Department of Education, and others (Lyons, 2006). To this day, Saskatchewan science curriculum documents are written and revised using a collaborative model (Molnar et al., 2019).

Janzen led curriculum revisions in the 1960s. As another, what might be considered revolutionary, approach, Janzen convinced the Department of Education to draw on the expertise of teachers, university experts, and other knowledgeable individuals in the creation of this curriculum (Lyons, 2007). This important introduction brought the responsibility of curriculum and curriculum change to awareness in the teaching community. It was with this collaborative mentality that the province of Saskatchewan established its approach to curriculum development.

In 1981, driven by a spirit of collaboration, Saskatchewan's provincial ministry created the Curriculum and Instruction Review (C & I Review) committee and tasked this committee with rethinking Saskatchewan's public education (McConaghy, 1990; Robinson, 2006). In 1984, the same year that *Science for Every Student* was released by the Canadian Government, the

Saskatchewan-based C & I Review committee produced its final report, *Directions* (Saskatchewan Education, 1984). In this report, the C & I Review committee recommended the development of an aligned core curriculum from grades K – 12 (Molnar et al., 2019).

Following the *Directions* report Saskatchewan Education (formerly the Department of Education) released the *Core curriculum plans for implementation* in 1987. This document outlined eight required areas of study, including science, and six common essential learnings. The common essential learnings were not intended to be considered new subjects but meant to inform all subject matter and how it was taught (McConaghy, 1990). Table 4 provides a summary of the required areas of study and common essential learnings included in this version of Saskatchewan's core curriculum.

Collaboratively developed, Saskatchewan's core curriculum was meant to change the way that Saskatchewan schools offered education. In this curriculum, students gained exposure to each of the eight required subjects and six common essential learnings (see Table 4) in increasing complexity throughout their educational careers (Robinson, 2006). The inclusion of the cross-disciplinary common essential learnings may not seem revolutionary today, but this was the first occurrence of Saskatchewan curriculum documents considering more than only

Table 4

Requirements of Saskatchewan's 1987 Core Curriculum

Required Areas of Study	**Common Essential Learnings**
Language arts	Communication
Mathematics	Numeracy
Science	Critical and creative thinking
Social studies	Technological literacy
Arts education	Personal and social values and skills
Health education	Independent learning
Physical education	
Practical and applied arts	

Note: Adapted from McConaghy, 1990; Robinson, 2006; Saskatchewan Education, 1987 subject content (Robinson, 2006). The common essential learnings were removed from those science curriculum documents produced after 2006.

The 1987 core curriculum moved Saskatchewan education from curriculum implementation to curriculum actualization, where teachers were meant to constantly revisit and revise how they used the curriculum document in their practice (Saskatchewan Education, 1999). This curriculum was referred to as the Evergreen Curriculum (Robinson, 2006). In its inception, the Evergreen Curriculum was meant to be regularly revised, as implied by actualization at a governmental level. Unfortunately, this was not the case, as shown by the 'Evergreen' Physics 30 document receiving its last revision in 1992 despite being used in practice until 2016.

The lag in revision to Saskatchewan's curricula could be due to many factors. Specifically, in science, the Pan Canadian Framework was released in 1997, just five years after the 1992 Saskatchewan Physics 30 curriculum document. Attempts to 'evergreen' the 1992 Physics 30 curriculum document (and other science curricula) were likely halted because these curriculum documents would become obsolete. The Saskatchewan Ministry of Education (formerly Saskatchewan Education) would soon overhaul the province's science curricula to align these documents with the Pan Canadian Framework. Despite not achieving a truly evergreen curriculum, the Saskatchewan Ministry of Education maintains Janzen's traditions in science curriculum development and implementation by consulting teachers, using writing groups, and asking stakeholder groups to review recently produced curriculum documents.

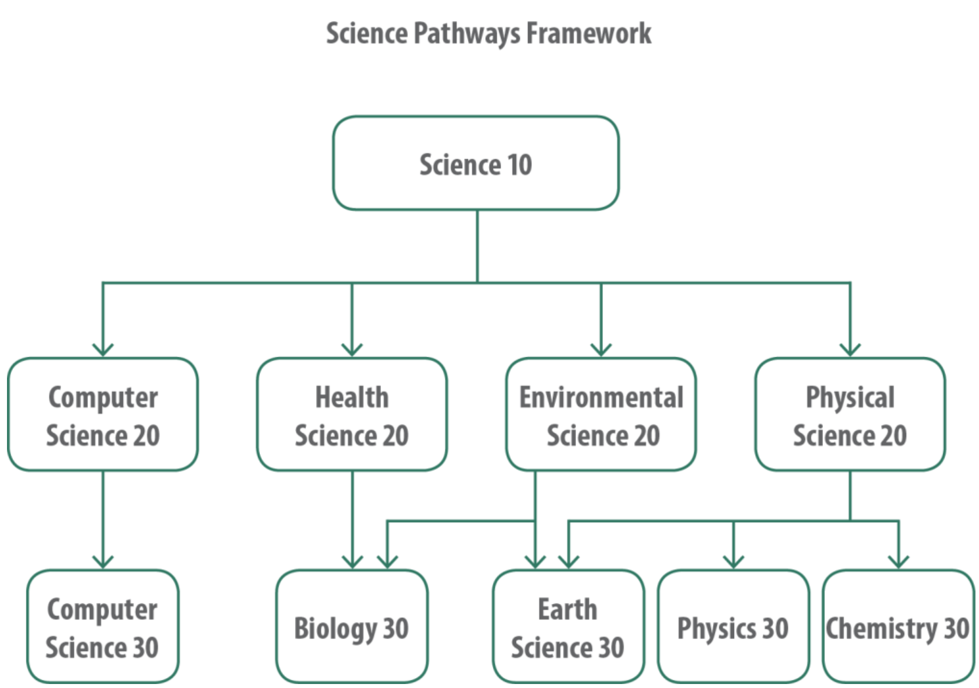
2.2.3. Comparing Saskatchewan's 1992 and 2017 Senior Physics Curriculum Documents

As with all of the Saskatchewan science curricula released after the Pan Canadian Framework, the 2017 Physics 30 document introduced some significant changes. The 1992 curriculum document represented both Physics 20 (grade 11 physics) and Physics 30 (grade 12 physics) courses. With the Pan-Canadian Framework driven revisions to the Saskatchewan science curricula, Physics 20 no longer existed and was replaced by Physical Sciences 20 (a combination of both physics and chemistry concepts) in an attempt to "provide students with opportunities to learn core [...] chemistry and physics disciplinary ideas within interdisciplinary contexts," (Ministry of Education, 2015, p. 3). Physics 30 was now a standalone curriculum document. As shown in Figure 3, students must take both Science 10 and Physical Science 20 as pre-requisites to Physics 30.

Both the 1992 Physics 30 curriculum document and the 2017 Physics 30 curriculum document included a connection to cross-curricular competencies. In the 1992 document, the six common essential learnings of Saskatchewan education (see Table 4) were described and connected to each unit of instruction. In the 2017 document, four cross-curricular competencies (thinking, identity and interdependence, literacy, and social responsibility) that students should

Figure 3

Science Pathways Framework for Saskatchewan Education (Ministry of Education, 2015, p. 3)



have developed in each area of study at each grade were described in each curriculum document before the listed units and topics (a.k.a. the 'front matter' of the curriculum document). The four competencies described in the 2017 document were not directly connected to any unit, outcome, or indicator. Teachers were expected to teach cross-curricular competencies with the outcomes listed in the 2017 Physics 30 curriculum document as they were with the common essential learnings in the 1992 document.

Written based on the Pan Canadian Framework, the 2017 Saskatchewan science curricula focused on scientific literacy. The areas of scientific literacy emphasized in the 2017 curriculum document included: (a) science knowledge, (b) STSE, (c) science skills, and (d) science inquiry. Each indicator in the 2017 Physics 30 curriculum document connected to at least one of the four areas of scientific literacy (see Table 1 for an example). Similarly, scientific literacy was a focus of the 1992 curriculum document for Physics 30. In the 1992 document, scientific literacy was described by seven dimensions (nature of science, key science concepts, processes of science, science-technology-society-environment interrelationships, scientific and technical skills, and values that underlie science), each supported by between 8 and 33 of what the writers called "Factors of Scientific Literacy" (for a total of 104 factors). Each unit in the 1992 document opened with a brief unit overview followed by a list of factors to be emphasized during that unit. Scientific literacy was represented differently within the 1992 and 2017 Physics 30 curriculum documents but was a focal point of both curricula.

In addition to describing how to emphasize scientific literacy, both the 1992 and 2017 Saskatchewan Physics 30 documents addressed instructional methods but in very different ways. The 1992 document discussed assessment techniques appropriate for physics instruction at length (6 pages), providing examples and possible templates for assessments. The 1992 Physics

30 curriculum document also provided a thorough “Unit Planning Guide” (pp. 55 – 56) and sample unit (pp. 57 – 77) for Physics 30. In the 1992 curriculum document, it was suggested that teachers use a variety of instructional methods including direct instruction (i.e., demonstrations or lectures), indirect instruction (i.e., concept-mapping or inquiry), experiential instruction (i.e., simulations or field trips), independent study (i.e., homework or reports), and interactive instruction (i.e., brainstorming or laboratory groupings). Teachers were encouraged to practice “resource-based learning” (p. 14) and integrate multiple resources to create student-centred learning experiences. One of the goals of the 1992 curriculum was that Physics 30 courses be “inquiry and activity based, with a strong emphasis on problem solving,” (p. 5) with the explicit indication that at least 20 hours of a Physics 30 course were dedicated to activities (Science Education, 1992, p. 6). Hour allocation was common in the 1992 document with each unit having a suggested number of hours, but the 2017 document contained no suggested hour allocation.

Within the 2017 Saskatchewan Physics 30 curriculum document, both inquiry and science challenges were described as recommended instructional approaches in the front matter of the document. To engage students in inquiry learning, the curriculum document described four “learning contexts,” (p.23) to be reflected in science classrooms: scientific inquiry, technological problem solving, STSE decision making, and using cultural perspectives. Each of the nine learning outcomes in the 2017 Saskatchewan Physics 30 curriculum document was connected to at least one learning context that teachers were expected to use to guide their instruction of that outcome. Both the 1992 and the 2017 Saskatchewan Physics 30 documents discussed instructional methods expected within a Saskatchewan Physics 30 course but emphasized different aspects of the expected teaching approaches.

The 2017 Physics 30 document was noticeably shorter than the 1992 document. The 2017 curriculum document was a total of 44 pages where the 1992 document was a total of 280 pages (including 84 pages of content to be taught in grade 11 physics). In the 1992 document, 55 pages described 244 learning outcomes to be taught within four required units. Teachers were also expected to teach at least one optional unit. The 2017 Physics 30 curriculum document contained five required units (with no optional units) containing nine overarching learning outcomes, which can be seen in Table 5. As previously mentioned, these nine outcomes were

Table 5

Program of Studies in the 2017 Saskatchewan Physics 30 Curriculum Document (2017, p. 30)

Unit: Student-Directed Study
Outcome:

- Create and carry out a plan to explore one or more topics of personal interest relevant to Physics 30 in depth.

Unit: Modern Physics
Outcomes:

- Analyze the importance of relativistic principles and quantum mechanics in our world.
- Assess the effects of radioactivity and applications of nuclear technology on society and the environment.

Unit: Forces and Motion
Outcomes:

- Analyze motion in one- and two-dimensions, including uniform motion, uniformly accelerated motion, circular motion and projectile motion.
- Analyze the effects of forces on objects undergoing uniform motion, uniformly accelerated motion, circular motion and projectile motion.

Unit: Conservation Laws
Outcomes:

- Investigate the nature of mechanical energy and efficiency in mechanical systems in relation to the law of conservation of energy.
- Analyze the motion of objects and interactions between objects using momentum concepts, including the law of conservation of momentum.

Unit: Fields
Outcomes:

- Investigate gravitational fields and their interactions with matter
- Investigate electric and magnetic fields and their interactions with matter.

supported by 97 indicators (approximately 10 indicators each). The 2017 Physics 30 curriculum document used 10 pages to share its outcomes and indicators with teachers.

As represented in Table 1 and Appendix A, the 1992 document provided much more detail to teachers regarding the concepts to be taught. For each topic in the 1992 curriculum document, teachers were provided with a description of the key concepts (including mathematical equations), a list of the learning outcomes, and up to 3 pages of teaching suggestions, activities, and demonstrations. In the 2017 curriculum document, teachers were provided with the outcome to be achieved by students and a list of supporting indicators which teachers may or may not have chosen to meet (as they had the discretion to meet the outcome as they saw fit). Given the differences in the required expectations, the 1992 Physics 30 curriculum document was much longer than the 2017 Physics 30 curriculum document.

The content of the 2017 Saskatchewan Physics 30 curriculum document was influenced by the 1992 Physics 30 curriculum document since the entire writing group had taught from this document for many years. However, the content of the 1992 Physics 30 course was not simply replicated in the 2017 document. Some topics in the 1992 document were moved to other science courses. For example, the topic of electric circuits had been 30 hours of instruction in the 1992 Physics 30 course but was moved into Science 9 with the post-Pan Canadian Framework science curricula. Similarly, motion analysis—allocated approximately 15 hours of the 1992 Physics 30 course—was taught in Science 10 in Saskatchewan's post-Pan Canadian science curricula. Other topics from the 1992 Physics 30 curriculum document were partially included, the concepts from these topics rewritten and moved under one of the existing outcomes. For example, the conservation of momentum—a topic in the optional applications of dynamics unit in the 1992 Physics 30 curriculum document—was combined with the concept of the conservation of energy—a topic in the required energy unit in the 1992 document—to create the unit teaching conservation laws in the 2017 Physics 30 curriculum document. Finally, concepts in some topics were included to fit under the new outcomes. For example, the concepts under the topic "Newton's Laws of Motion" from the 1992 document were included under the "Forces and Motion" outcomes in the 2017 Physics 30 document. These revisions and changes to content have been represented in Table 6.

*2.2.4. Summarizing the Context of Curriculum Developmen*t

Resulting from a province-wide, K-12 renewal to reflect the structure of the Pan-Canadian Framework, the Ministry of Education in Saskatchewan released a Physics 30 curriculum document in the fall of 2016, which was revised and re-released in 2017. As had happened in Saskatchewan since the mid-1940s, a group of teachers and advisors from Ministry of Education collaborated to devise the content of this curriculum document; I was privileged to be a part of this working group for the Physics 30 curriculum document. The front matter of this document, as with all of the Saskatchewan science curricula, was the responsibility of the curriculum writers from the Saskatchewan Ministry of Education (not the teacher writing group) and had been guided by the Pan-Canadian framework. As writers, we were able to reorient the concepts and content of the 2017 curriculum document given that they followed the outcome-indicator format of the Pan-Canadian framework and met its philosophy as interpreted for the Saskatchewan science curriculum. The Saskatchewan Ministry of Education, assisted by this writing group, produced a document that looked very different from the 1992 Physics 30 curriculum document.

Table 6

Program of Studies in the 1992 Saskatchewan Physics 30 Curriculum Document (p. 165)

Unit: Kinematics & Dynamics (30 hours)
Topics:

- Understanding Motion (Graphical Kinematics)$^+$
- Vector and Scalar Quantities$^+$
- Distance and Displacement$^+$
- Speed and Velocity*$^+$
- *Acceleration*
- *Newton's Laws of Motion*

Unit: Mechanical Energy (10 hours)
Topics:

- *Work*
- *Power*
- *Kinetic Energy*
- *Gravitational Potential Energy*

Unit: Electricity (20 hours)
Topics:

- Applications$^+$
- Current and Potential Difference (including Ohm's Law) $^+$
- Electric Circuits$^+$
    - Kirchoff's Laws$^+$
    - Series and Parallel Circuits$^+$
- Electric Power and Energy$^+$

Unit: Nuclear Physics (15 hours)
Topics:

- *Natural Radioactivity*
- *Nuclear Fission*
- *Nuclear Reactors*

Optional Units:

- ***Applications of Kinematics and Dynamics***
- **Fluid Mechanics**
- ***Electromagnetism***
- **Atomic Physics***

Key:
Italicized topics and optional units in the 1992 document were entirely (or close to entirely) included in the 2017 document
* indicates topics and optional units in the 1992 document that were partially included in the 2017 document
$^+$ indicates topics and optional units in the 1992 document that were primarily moved to other science courses

2.3. Educational Change and Teacher Concerns

It is rare to find a science teacher who has had a long career without experiencing curriculum change (Ryder et al., 2014); as our world changes, so does education. Sun et al. (2015) offered a Western-Canadian example of this change when they examined the changes to the British Columbia science curriculum and found no less than six shifts between child-centred and subject-centred curricula between 1920 and 2014, with three of these shifts occurring after 1983. These three shifts likely occurred because of attempts to standardize science education in Canada as evidenced by three major implementations: the release of *Science for Every Student* (SCC, 1984), internationally standardized examinations such as the TIMSS testing, and the Pan-Canadian Framework (CMEC, 1997). Similarly, senior science teachers in Saskatchewan have experienced three different curriculum structures since 1983 with new curriculum documents released in the early 1990s (1992 for Physics 30) and 2010s. Given the increasingly occurring shifts in science curriculum, as evidenced by Sun et al. (2015), educational change should be of concern—or at least of interest—to educational researchers in Western Canada.

Change in education may occur in repeating patterns; some have called the constant change in education the 'education pendulum' (Ryder et al., 2014). It is common to hear experienced teachers say, "just wait a few years and things will swing back the other way", since—to them—educational change is constantly expected. This may explain why, in some studies, teachers with relevant experience were less likely to be concerned when implementing a new course curriculum (Kwok, 2014; Yan & Deng, 2019). Teachers are no strangers to change, particularly those with significant field experience. Nevertheless, teachers of any experience level might resist change.

In the field of education, new information on teaching regularly emerges, yet, “while some may embrace change and see it as an opportunity [...], others may doubt its effectiveness and see it as a threat to their profession” (Kwok, 2014, p. 44). If a teacher perceives change as threatening in any way they are more likely to resist embracing this change, choosing to remain in the familiar (Hall & Hord, 2015). When new information contests current beliefs regarding teaching and education, teachers may begin to question current (and previous) practices and beliefs and even avoid information that challenges their existing professional knowledge to evade vulnerability (Le Fevre, 2014). It may be easier to continue in perceived success than to accept challenges to our ontological and epistemic beliefs.

Teacher efforts to maintain the status quo, whether they be to avoid, to challenge, or to maintain perceived success, can greatly impede reform efforts. According to Tytler (2010), science teachers can hinder curricular reform since they may have been shaped through “mastery of canonical content” and often align their epistemic beliefs with this mentality (p. 973). Such teachers learned to accept a certain emphasis, or viewpoint, of what constitutes science. However, part of being a science teacher today is accepting that we are not the keepers of content (Watson, 2017). To change a longstanding, systematically held belief, such as the teacher as the ‘master’ of science content, a challenge needs to be made not only to teachers’ beliefs but also to those beliefs inherent in ‘traditional’ science education.

Resistance to change might also be attributed to a culture of privatization amongst classrooms. Le Fevre (2014) and Lortie (1975) discussed teachers’ reluctance to publicize practice in education. Teachers often feel as if they are expected to be experts in their classrooms (Watson, 2017) and may view the risk of change to be too great, particularly with respect to how they will be viewed within the community (both internal and external to the education system).

Be that as it may, in their study Lowe and Appleton (2015) found that some teachers sought other colleagues for assistance when implementing a new science curriculum. The decision of whether to seek help may stem from the strength of the learning community in both the subject and the school (Fullan, 2016). Change does not have to be handled alone but it often is.

Teachers may be reluctant to accept reform for many reasons, but change need not be feared. Teachers, much like the world, must respond to the ever-changing environment in which they practice. If teachers do not increase their capacity to handle change, "they [may] continue to be victimized by the relentless intrusion of external change forces" (Fullan, 2016, p. 107). Educational change is not only inevitable; it is necessary (Fullan, 2016). Still, change can be reluctantly received in many educational contexts.

Teachers are key agents in educational change (Ashraf, 2019; Fischer et al., 2019; Gaith & Shaaban, 1999), and their concerns directly impact their response to change (Gudyanga & Jita, 2018; Kwok, 2014). As Le Fevre (2014) explained, when teachers' beliefs[5] are contested, they are likely to resist change. Since concerns may arise from questioning one's beliefs[6] (van den Berg & Ros, 1999), these concerns may reveal important influences on teacher responses to a new curriculum. In light of this information, I asked whether potential connections existed between teachers' concerns about the 2017 Saskatchewan Physics 30 curriculum document and teachers' epistemic beliefs about physics knowledge.

[5] Le Fevre (2014) discussed teachers' beliefs and reasons for engagement with a specific initiative, not teachers' epistemic beliefs.
[6] van den Berg and Ros (1999) do not explicitly discuss epistemic beliefs but instead attribute beliefs to be an indicator of the values and attitudes a teacher holds about teaching.

2.3.1. Defining Concerns

Teacher concerns became part of the educational research landscape around 1969 with the work of Frances Fuller. While studying the concerns of beginning teachers, Fuller (1969) introduced the idea of *concerns* as encompassing one's feelings and perceptions. Within her study, she explored the concerns of student teachers, that is, what they were concerned about when it came to teaching. She correlated her findings with other studies investigating areas such as teacher satisfaction, proficiency, and worries.

In her seminal work, Fuller summarized her views into a model where teacher concerns were grouped into three major areas: concerns about self, concerns about tasks, and impact concerns. *Concerns about self* are personal concerns a teacher has regarding impact on themselves. For example, a teacher might worry about personal adequacy, whether they fully understand a concept, or how their employment reviews will be impacted. The teacher in this area is concerned with how they will be impacted as an individual. *Concerns about tasks* relate to the daily activities of a classroom such as student behaviour, class control, or classroom organization. For example, a teacher might be concerned about how they will teach the content in a new curriculum document. Finally, *impact concerns* are focused on the impact of change on their pupils and community. An example of this could be a teacher's concerns about a new curriculum primarily focusing on student learning or student preparation for the next stage in education. Teacher concerns, according to Fuller, could be classified and understood as emotional responses and worries related to teaching regarding oneself, one's tasks, or the impact on one's students and community.

Since Fuller's study, teacher concerns have been studied in other contexts, but the definition remains like that of Fuller's; concerns are emotional responses and perceptions.

According to van den Berg et al. (2000), "concerns refer to those problems or questions, which arise with more or less of an emotional undertone in response to new situations that may signal feelings of uncertainty and possible resistance" (p. 332). The experiences that teachers undergo when required to change can evoke feelings and perceptions expressed as concerns (Hall & Hord, 2015; van den Berg, 1993; Yan & Deng, 2019). These concerns manifest as the questions, resistances, and uncertainties experienced by teachers when encountering something new (van den Berg & Ros, 1999). According to Hall et al. (1979), "in response to the demand [of a new innovation], our minds explore ways, means, potential barriers, possible actions, risks and rewards in relation to the demand" (p. 5). Aligning with the literature in this area, I viewed teacher concerns as emotional responses, questions, worries, and uncertainties.

2.3.2. Research about Teacher Concerns and New Science Curricula

Studies with science teachers have found concerns related to changing content in curricula (e.g., Boergerding et al., 2013; Gabby et al., 2017; Ryder & Banner, 2013), uncertainty with innovations (e.g., Geng et al., 2019; Gudyanga & Jita, 2018; Ryder et al., 2014) and concerns with alignment between assessment practices and intended curricula (e.g., Abadie & Bista, 2018; Gabby et al., 2017; Ryder et al., 2014). Each study investigated science curricular reforms, yet, none of these studies were situated in the Canadian context and only two studies represented a North American perspective (see Boergerding et al., 2013; Abadie & Bista, 2018). "Different teachers in different contexts will have different concerns," (Fischer et al., 2019, p. 25); hence, this study added another context—the Western-Canadian perspective—to this body of literature.

2.3.2.1. Content Changes. In 2014, England officially released a new national curriculum with the intention of all subjects and grades implementing new curriculum documents in the fall of 2015. As this curriculum was being released, Ryder and colleagues (2013, 2014) found that teachers reported concerns about a lack of content in the new English science curriculum. Ryder and Banner (2013) claimed this concern regarding a lack of content was likely due to the shift from information-delivery to an emphasis on the nature of science, and that this shift forced teachers to rethink what it meant to teach science. ‘Content’ is dependent on the goals of a science curriculum (DeBoer, 2000), and a shift in these goals would mean a change in content. However, science teachers often see themselves as guardians of content as well as of the ways of knowing science (Tytler, 2010); science teachers often believe that it is their ‘duty’ to ensure science is taught properly. As such, teacher concerns may be connected to misinterpreting the ‘content’ in a science curriculum, especially if the goals of a new curriculum document challenge personal orientation regarding content in science.

In curriculum change, the literature also discusses concerns related to the inclusion of ‘new’ content, or content not previously taught in that course or by that teacher. For example, in a study conducted with 28 American teachers implementing a new biotechnology curriculum, Boergerding et al. (2013) found that some teachers were concerned about teaching the content introduced in this new course. These teachers were concerned about having limited background knowledge in the newly included topics and felt poorly prepared to teach these topics, particularly those who were deemed to be novice teachers. Similarly, Gabby et al. (2017) found that a teacher with a low level of content knowledge in chemistry was more likely to focus on personal stages of concern. These findings reflect the importance of considering both one’s epistemic beliefs about, and understanding of, content in science when teaching with a new curriculum document. Further, according to Kwok (2014) and Lowe and Appleton (2015), when teachers with a lack of subject knowledge were asked to work with new content, they were likely to voice concerns focused on the self. A teacher's view of the content to be emphasized, their personal understandings of subject knowledge, and their preparation to teach a subject all influenced the concerns that a teacher might express in these studies.

2.3.3.2. Uncertainty. Uncertainty, in this study, referred to teachers' uncertainty regarding the direction of (and content within) a new curriculum document or other innovation. Uncertainty has been found to influence teachers' concerns when implementing new innovations. As one example, when studying science teachers' self-efficacy, Geng and colleagues (2019) found that Hong Kong teachers felt woefully unprepared for science, technology, engineering and mathematics (STEM) education (5.53% of respondents felt "well prepared"). Their study also found that those teachers feeling less prepared to teach STEM tended to have stronger personal and management concerns than their more prepared colleagues (Geng et al., 2019). Christou et al. (20014) found that when a teacher had substantial concerns about uncertainty, they often considered themselves unqualified to implement the desired innovation and, consequently, voiced stronger concerns about the innovation. Teachers in studies conducted by Le Fevre (2014) and Lowe and Appleton (2015) tended to hold fast to that which they were certain when encountering uncertainty. According to these studies, to remain in the familiar, a teacher—when viewing a new curriculum document—might focus on those areas compatible with their epistemic beliefs about a subject. Finally, Gudyanga and Jita (2019) found some teachers, when uncertain about their role in curriculum reform, focused their efforts on another aspect of teaching instead of focusing on the curriculum implementation (Gudyanga & Jita, 2019). According to the literature, if a teacher was uncertain in their ability to implement a new curriculum document, uncertain with their role in the implementation process, and/or uncertain in their level of understanding of the content, concerns were likely to surface.

Additionally, studies have found that concerns about an innovation were more likely if a teacher expressed uncertainty regarding whether the innovation would improve student learning. In studies (e.g., Le Fevre, 2014; Ryder & Banner, 2013; Ryder et al., 2014), teachers indicated they were more willing to change to accommodate the implemented innovation if they believed it would help their learners. Another belief reported by Kwok (2014) to strongly influence teacher concerns was whether a teacher believed they could successfully implement a new curriculum. Ryder & Banner (2013) also found that teachers were less likely to exhibit personal concerns and more likely to focus on learners when they believed they could be successful with an innovation. Uncertainty about an innovation, such as a new curriculum document, has been shown to fuel teachers' anxieties.

2.3.2.3. Reconciling Intended Curricula with Assessment Practices. Teachers in several studies expressed frustration with ill matched curricula and external examinations (e.g., Abadie & Bista, 2018; Gabby et al., 2017; Ryder & Banner, 2013; Ryder et al., 2014). With the 2014 release of a new national curriculum, teachers in England clung to teaching information instead of teaching socio-scientific issues and the nature of science as their new curricula intended; Ryder and colleagues (2013, 2014) attributed this to teachers' aims of preparing students for external examinations. Stadermann et al. (2019) reflected these sentiments when they explained that the nature of science and socio-scientific issues are much more difficult to assess on these types of exams since, often, there is no 'right' or 'wrong' answer. Similarly, Gabby et al. (2017) found that teachers lacking confidence in their science knowledge were more likely to teach in such a way that their students would score well on matriculation exams, independent of what the curriculum intended. As shown by the literature, teachers expressed concerns when external examinations did not align with the intended orientations of the government-mandated curriculum documents.

Other studies have reported that new curriculum documents concerned science teachers when their capabilities were judged based on students' performance in exams. Boergerding and colleagues (2013) found that Floridian teachers concerned about teaching biotechnology were not only concerned about the content but also that a new area of content would be present on their science-related external examinations. In Boergerding et al.'s context, teachers' capabilities were judged on their students' performance on these exams; hence, teachers felt pressured to ensure students were prepared to perform well. In another study (Gabby et al., 2017), teachers in private schools in Israel were less likely to be concerned with government-mandated assessment than their public school-based colleagues. Gabby et al. (2017) claimed that teachers in private schools may have been less concerned with government-mandated assessment because these schools used separate teacher evaluation and accountability systems. Unlike the public schools in Israel, teachers in private schools were not judged based on how many students achieved a specific score on an external exam. When curricular changes were strongly tied to the assessment of teachers, studies found teachers to be concerned about curricular reform on which their students (and by extension they) will be assessed.

The literature on science teachers' concerns regarding curriculum changes has identified some potential areas of concerns: (a) changing content in curricula, (b) uncertainty with innovations, and (c) concerns with alignment between assessment practices and intended curricula. To further the work in this field, I investigated the concerns of physics teachers in a Western-Canadian context, looking for what areas of concern they shared. In order to organize these areas of concern, a widely used framework in the field of concerns research, the Stages of Concern Framework, was employed.

2.3.3. Analyzing Concerns using the Concerns Based Adoption Model

To answer the question, “What were the concerns of Saskatchewan Physics 30 teachers regarding the 2017 Physics 30 curriculum document?” the well-established stages of concern framework was used. The stages of concern framework is one of three diagnostic dimensions within the Concerns Based Adoption Model (CBAM) as conceived by Hall et al. (1973). The Concerns Based Adoption Model (CBAM) arose from research and practice during the early 1970s and has been used for almost 50 years to measure, describe, explore, and explain teacher’s experiences during curricular change (Anderson, 1997; Hall & Hord, 1987). CBAM provides a language and means of organization to those feelings, anxiety, and questions—which often manifested as concerns (van denBerg & Ross, 2000) —that teachers experience during change (Hall & Hord, 2015), making it a convenient and accepted way to analyze teacher concerns through a process of change. With three main assumptions, (a) change is a process, not an event, (b) change is personal and involves developmental growth, and (c) change can be facilitated, (Anderson, 1997; Borgerding et al., 2013; Hall & Hord, 1987, 2015; Hall et al., 1973), CBAM offers a tested and well-developed theoretical model from which to explore teacher concerns.

CBAM uses three diagnostic dimensions to explore change: *levels of use, innovation configurations*, and, *stages of concern* (Anderson, 1997; Hall & Hord, 1987, 2015; Hall, et al., 1973). *Levels of use* measure general patterns employed by teachers as they interact with, and grow in, their use of innovations. Innovations are, often externally, mandated changes that can refer to school initiatives, change to a curriculum or curricular material, reformatting of the school environment, or any other innovation changing the way teachers are asked to approach their classroom practice. To describe innovations and patterns used within practice, one could apply diagnostic tools related to *innovation configurations*. Finally, the *stages of concern framework* categorizes teachers' concerns regarding the implementation of innovations. This study used the stages of concern aspect of CBAM since I was focused on teachers' concerns and not their current use of the curriculum document.

In 1969, Frances Fuller, released the first model used to analyze teacher concerns. This model categorized teachers' concerns into three phases of development: concern with self, concern with tasks, and concern with pupils. Hall et al. (1973) extended Fuller's stages of concern into seven progressive stages to create the stages of concern (SoC) framework. Labelled stages 0 through 6, these seven stages, as rephrased by Anderson (1997), are:

(0) *Unconcerned:* the teacher is not interested in, unaware of, or has little knowledge of the change;

(1) *Informational:* the teacher wants to learn more about the change and its implications. The teacher begins to learn about the change;

(2) *Personal:* the teacher is anxious about their role in the innovation. While the teacher may participate, they are not overly interested in the innovation;

(3) *Management:* the teacher begins to explore the innovation and focuses concerns on logistics;

(4) *Consequence*: the teacher concerns shift to focus on the impact the new innovation will have on their students and how to modify the innovation to fit personal practice;

(5) *Collaboration:* the teacher begins to show interest in working with others to embrace change and attempt implementation to best improve local context;

(6) *Refocusing:* the teacher has deeply considered the innovation and concerns revolve around modifying innovation to reap even more of the intended benefits.

The SoC framework presents seven distinct stages and these stages can be organized per Fuller's original model (Hall & Hord, 2015). In this connection, stages 0, 1 and 2, fall under self-concern as teachers within these stages express concerns regarding how implementation will directly impact them and their ability to succeed. Stage 3 relates to concerns with tasks; the teacher is focused on how this innovation will impact their classroom activities and tasks. Finally, stages 4, 5, and 6, represent those concerns related to impacts on peers and pupils; teachers are concerned with how the innovation will directly impact their students, student learning, and peer interaction with the innovation. These stages of concern and their relation to concerns related to self, task, and impact can be seen in Table 7.

These stages of concern offer a framework for viewing teacher concerns with curriculum implementation. "The stages of concern framework present a possible, not a necessary, progression of teacher concerns about a change" (Anderson, 1997, p. 334). For example, while a teacher may reach stage 6, it is most common for teachers to reach the stage of collaboration and operate functionally within the new innovation (Anderson, 1997). Additionally, research has found that teachers do not necessarily follow the progression depicted by the SoC framework (Gabby et al., 2017; Kwok, 2014), and teachers can hold concerns in several stages at one time (Gudyanga & Jita, 2018). The term 'stages' as well as the represented levelling of these stages (i.e., stage 5 is a 'higher' stage than stage 2) are used to maintain consistency with the literature and research about teacher concerns, but it is recognized that this does not imply an assumed, linear progression of teachers from stage 0 to stage 6.

Table 7

Summary of the Stages of Concern (adapted from Hall & Hord, 2015)

Fuller's Original Model	Stages of Concern	Expression of Concern
Concerns with Self	0. Unconcerned	I am more concerned about other things.
	1. Informational	I would like to know more about it.
	2. Personal	How will using it affect me?
Concerns with Tasks	3. Management	I seem to be spending all my time getting materials ready.
Concerns Related to Impacts on Peers and Pupils	4. Consequence	How is my use affecting students?
	5. Collaboration	I am concerned about relating what I am doing with what my colleagues are doing.
	6. Refocusing	I have some ideas to use this that would work even better.

The SoC framework, as originally conceived by Hall et al. (1973) has been widely accepted as one of the most reliable measures for teacher concerns with implemented curricular materials and practices (Anderson, 1997; Gabby et al., 2017; Gudyanga & Jita, 2018; Hall & Hord, 1987, 2015; Kwok, 2014). The original version of SoC has been widely adopted and adapted, but it has been suggested further studies are needed to refine the model (Anderson, 1997; Kwok, 2014; Shotsberger & Crawford, 1999). One of Kwok's (2014) major criticisms of the SoC framework is its neglect to include context within the model. If change is a deeply personal experience (Fullan, 2016), as claimed by the main assumptions of CBAM and the SoC framework (Hall & Hord, 1987, 2015), one should seek to include context within the model. To this end, Gabby et al. (2017) caution against relying solely on the quantitative approaches with the SoC framework and recommend the use of interviews to improve data richness. To minimize the potential effects of decontextualization by the SoC framework, this study included contextual elements surrounding the concerns presented by teachers including themes specific to this group of interviewed teachers such as concerns regarding accreditation of grade 12 teachers in Saskatchewan.

2.3.4. Summary of the Teacher Concerns' Literature Review

Studied in educational literature for approximately 50 years, starting with the work of Fuller (1969), teacher concerns can be defined as one's feelings about, worries regarding, and perceptions of the potential impact of educational change. Teachers are well acquainted with change, yet change is not always well received. Resistance is common when teachers feel threatened by an incoming innovation, often manifesting as attempts to maintain the status quo. In science education, studies have shown that teachers express concerns when they question the content in the curriculum, when they are uncertain about the curriculum, and when government-mandated assessment is connected to any changed curricula. This study sought to further these findings by exploring teachers' concerns specific to the implementation of a senior physics curriculum document in Western Canada.

The stages of concern (SoC) framework, a part of the Concerns Based Adoption Model (CBAM) designed by Hall et al. (1973), was used to conceptualize and analyze teacher beliefs in this study. As shown in section *2.3.3. The Stages of Concern Framework*, this framework has been well documented and frequently used in research investigating teachers' concerns. Contributing to the recent work of the Saskatchewan Teachers' Federation (STF) (2018, 2019), which explored the configuration of Saskatchewan's renewed curriculum (and curriculum renewal process), this study sought to recognize teachers' concerns about a specific curriculum document (Physics 30). Understandings of these concerns in the Saskatchewan context could provide a starting point for investigating teachers' concerns regarding other curricula in this province since, according to the STF (2018, 2019), after curriculum documents are fully released in Saskatchewan, the majority of teachers are not asked for their opinions about these curriculum documents.

2.4. Literature Review Summary

This chapter discussed the literature and contexts informing this study. Epistemic beliefs were defined as an individual's beliefs about their conceptualization of knowledge. Epistemic beliefs about physics knowledge in this study were considered to be informed by four areas: epistemic beliefs about (a) the structure, (b) the source, (c) the certainty, and (d) the content of physics knowledge. Each of these four areas has been described by a continuum lying between two extreme beliefs. An individual might believe that physics knowledge is structured as a collection of isolated ideas, a coherent system of connected ideas, or a combination of the two. Epistemic beliefs about the source of physics knowledge describe the degree to which an individual views physics knowledge as preexisting in an external reality, waiting to be discovered or as invented by humanity. Epistemic beliefs about the certainty of physics knowledge describe the degree to which an individual believes that physics knowledge is absolute and unchanging or tentative and subject to change. Finally, an individual's beliefs about the content of physics knowledge can be described as mathematically-oriented, as qualitative and conceptual, or as a combination of both. A discussion of epistemic beliefs as filters and recent research conducted with students regarding epistemic incongruences showed the potentialities for misalignment of epistemic beliefs about physics knowledge between teachers and the curriculum documents from which they teach. The literature review about epistemic beliefs concluded with describing the conception of these four areas as a theoretical framework for data analysis. It is with this framework and knowing that epistemic beliefs about physics knowledge may vary among teachers that this study asked, “What were Saskatchewan Physics 30 teachers’ epistemic beliefs about physics knowledge?”

As this study considered the 2017 Physics 30 curriculum document in Saskatchewan, section *2.2. The Context of Developing the 2017 Saskatchewan Physics Curriculum* discussed curriculum and its development in this context. ‘Curriculum’ was defined as the intended curriculum, specifically a curriculum document. A brief history of science curricula in Canada explained that curriculum documents are mandated by provincial governing bodies and most science curricula were informed by the Pan Canadian Framework. A description of curriculum development in Saskatchewan highlighted the historic importance of Saskatchewan government officials involving various stakeholders including subject area specialist teachers in the writing of curriculum documents. Finally, the 1992 and 2017 Saskatchewan Physics 30 curriculum documents were compared.

Section *2.3. Educational Change and Teacher Concerns* outlined educational research regarding teachers’ concerns. Teachers’ concerns were defined as the problems, questions, anxieties, or worries that surface as a response to innovations that may indicate uncertainty with or resistance to said innovation. Research investigating teachers’ responses to new science curricula was summarized and three common underlying areas common to these studies were explained; these three areas were: (a) concerns related to content changes, (b) uncertainty with new curricula, and (c) concerns regarding ill-aligned assessment and curricula. As Saskatchewan Physics 30 teachers were experiencing a change in curriculum, from the 1992 to 2017 documents, at the time of this study, I also asked, “What were Saskatchewan Physics 30 teachers’ concerns about the 2017 Physics 30 curriculum document?”

Even with this existing body of knowledge, I was left wondering, could teachers’ concerns regarding the 2017 Saskatchewan Physics 30 curriculum document be connected to their epistemic beliefs about physics knowledge? I proposed that a teachers’ interpretation of the curriculum document, influenced by their epistemic beliefs about physics knowledge, might be associated with concerns and that these connections could provide insight into the implementation of physics curricula in this context. To investigate this conjecture, this study explored Saskatchewan grade 12 physics teachers’ concerns regarding the 2017 Physics 30 curriculum document by asking, “Were there connections between teachers’ epistemic beliefs about physics knowledge and their concerns with the 2017 Saskatchewan Physics 30 curriculum document?”

By investigating the three identified research questions, this study contributed to (a) the relatively non-existent literature investigating teachers’ concerns about physics curricula (as opposed to general science curricula), (b) the growing body of science education literature in Canada (Milford & Tippett, 2019), (c) expanding the educational research available regarding teachers’ epistemic beliefs about physics knowledge (as most studies focus on epistemic beliefs about science knowledge), and (d) identifying potential connections of the previously non-connected, but well-established, literary fields of teachers’ epistemic beliefs and teacher concerns. Through this study, I aimed to further the understanding of the impact that epistemic beliefs about knowledge might have on curriculum interpretation by identifying potential connections between teachers’ epistemic beliefs about physics knowledge and their concerns about a curriculum document. This understanding could inform the implementation of future curriculum documents and education of future, epistemically-aware science teachers. This study extended the work of previous scholars' investigations by looking specifically at the concerns of teachers as they may be connected to those epistemic beliefs about physics knowledge that are held by teachers in a Western-Canadian context.

CHAPTER 3: METHODOLOGY

This chapter opens by describing the epistemological and ontological positions underpinning this study. Following this, the research methodologies historically used in investigating epistemic beliefs and teacher concerns are explained. The mixed methods design conceived originally for this study did not unfold as anticipated. Therefore, to provide context regarding the methodological decisions, to explain the eventual methods used, to showcase the trajectory of the study, and to be honest about this research, the research design is presented as a historical evolution of the data collection and analysis. Finally, the approaches to ensure the quality and ethical execution of this research are discussed.

3.1. Epistemological & Ontological Orientations of this Research

A research paradigm guides any researchers' understandings of what could be known, as well as how knowledge was understood and could be gathered (Grix, 2004). Historically, there are two major paradigms utilized in social science research: positivism and interpretivism, which is also known as constructivism (Grix, 2004; Guba, 1990). These two paradigms are often considered as oppositional to each other. Positivism is rooted in realist ontology, meaning the world is viewed as existing independently of personal knowledge (Grix, 2004; Guba, 1990; Usher, 1996). Characteristically, this paradigm uses empirical data and logical reasoning to produce—what are considered to be—objective and generalizable understandings (Treagust et al., 2014); there is little or no room for relativism or consideration of personal interpretation and contextual situations. Admittedly, I operated with some positivist tendencies throughout this study, since I used *a priori* frameworks. Yet, I do not orient myself toward a single, knowable truth. Rather, I accept that these frameworks are predetermined as well as biased by myself and those who have used and interpreted these frameworks before me. That is, they were constructed by people to try to make sense of a phenomenon. As epistemic beliefs and concerns are both highly individualized, contextual processes, influenced by my assumptions and beliefs as well as those of my participants, a positivist position would have been inappropriate for this study.

Interpretivism is most appropriate when considering human actions as it provides consideration and inclusion of both the action and the context in which it exists (Treagust et al., 2014; Usher, 1996). To the interpretivist, reality is constructed by humanity and is local and specific to each person (Guba, 1990; Lather, 2006; Treagust et al., 2014). All human understanding and actions are “immersed and inseparable from a network of culturally-conditioned beliefs and practices, assumptions, and presuppositions” (Usher, 1996, p. 20). Within this relativistic ontology, reality exists within one’s construct only viewable and understandable through personal experiences. Thus, knowledge is never value-free but always situated by the knower (Guba 1990; Treagust et al., 2014). This sentiment echoes a view central to this study; epistemic beliefs operate as a filter through which the world is viewed. One’s interpretation of the world, much like the interpretation of a curriculum document, is never value-free. Research investigating both teacher concerns and epistemic beliefs is heavily laden with values and personal understandings, as both areas entail interpretation on behalf of the participant as well as the researcher. Teacher concerns and epistemic beliefs are both concerned with reality in a socially-determined, value-driven context, and do not exist as an objective reality separate from the knower. Hence, this relativistic ontology, where it is assumed that one’s reality is a construction that is based on experiences, interconnected with beliefs, practices, assumptions, and understandings of the world they encounter, was appropriate for this study.

Epistemologically, interpretivism operates with a subjectivist focus where knowledge is created through the interaction of knower and phenomenon (Guba, 1990). Knowledge, in this paradigm, means to know differently as opposed to being a result of accumulating information (Usher, 1996). As knowledge exists specific to a person's reality (Guba, 1990), it was understood within this study that each person's reality might vary, as does knowledge. This variance deeply impacts interpretivism-oriented research and I had to remain constantly aware of the subjective nature of knowing and knowledge. As one example of reflecting this awareness in academic work, Peshkin (2000) used problematics to show that interpretation requires the researcher to choose where to look, to judge what types of evidence to collect, and to recognize their own subjectivity. Adapting such an anthropic approach, the researcher will naturally set limitations on the conditions they are likely to observe; observations are limited to those conditions within a researcher's reality (Carter, 1974). These limitations and subjectivity make it difficult (if not impossible) to remain objective in interpretivist research (Treagust et al., 2014), therefore, one must recognize their situatedness throughout their research (Usher, 1996).

Methodologically, interpretivism focuses on understanding a phenomenon as opposed to attempting an explanation for the reasons behind its occurrence (Grix, 2004; Usher, 1996). Methods within this paradigm are often hermeneutic in nature, where data is collected, refined, compared, and contrasted. In comparing and contrasting this data, the researcher seeks to develop findings through considering vantage points that cohere, but that may or may not be identical (Guba, 1990). Throughout this process, findings often impact participants while participants also impact findings, producing a circular process of research (Lather, 2006).

The *double hermeneutic*, an interpretation based on one's interpretation (Grix, 2004; Usher, 1996), contributes to this circular metaphor of research. Research involving the double hermeneutic has been criticized as producing results that are not necessarily generalizable to other studies as interpretation is made on interpretations (Treagust et al., 2014), increasing the level of inference within such research. As an interpretivist researcher, I was not looking for generalizability but was looking to provide a context-rich understanding of these phenomena in a specific setting. I recognize that I operated within multiple layers of interpretation – participant from self, participant to researcher, researcher to reader, etc. Due to these layers of interpretation, the results of this study may be used to inform similar research but not necessarily predict what will occur. As value-free analysis is impossible within this paradigm (Grix, 2004; Treagust et al., 2014), this study described physics teachers' epistemic beliefs about physics knowledge and concerns within a particular context, Saskatchewan, at a certain point in time; spring 2018.

Finally, as interpretivism operates within a relativistic ontology and subjective epistemology, it may be susceptible to contradictions and internal inconsistencies produced within interpretivist explanations (Grix, 2004). To add to this issue, researchers are only able to interpret the evidence given to them by participants and need to be aware of unintended inferences being made (Treagust et al., 2014). It was imperative that I remained aware of personal constructs and understandings, while continually comparing, contrasting, and revisiting data as well as the interpretations being made and informing literature to fully integrate my changing expectations throughout the study (Guba & Lincoln, 1989; Treagust et al., 2014). Consequently, I needed to be rigorous in employing interpretivist-appropriate measures of credibility, such as progressive subjectivity checks and member checks (Guba & Lincoln, 1989). Credibility and how it was applied this study is discussed in section *3.5. Quality in Qualitative Research.* Being attentive to these measures of credibility, combined with a familiarity of the epistemic beliefs about physics knowledge framework and the stages of concern framework as defined in sections *2.1.4. Conceptual Framework for Analyzing Epistemic Beliefs about Physics Knowledge* and *2.3.3. Analyzing Concerns using the Concerns Based Adoption Model,* I sought to provide interpretations of participant responses that represented teachers' beliefs and concerns as precisely, honestly, and transparently as possible.

3.2. Historical Contexts of Research Methods

3.2.1. Researching Epistemic Beliefs

Perry's (1970) investigations of students' views on knowledge as they enter and progress through their early college years have been accredited with being the origins of epistemological beliefs research in education (Muis, 2008; Schommer, 1994b; Schraw et al., 2017). According to Muis (2008), it is since this work that "the study of epistemic beliefs has become one of the fastest growing areas of research in educational psychology" (p. 178). Epistemic beliefs, which are primarily studied within educational psychology, are an important factor in educational processes (Schommer, 1994b). Ergo, it is feasible (and prudent) to consider epistemic beliefs about physics knowledge in areas of educational research beyond educational psychology.

Since Schommer's (1990) pursuit of a quantitative approach to epistemic belief measurement, it has become increasingly acceptable to use quantitative surveys in epistemic belief research. Studies investigating epistemic beliefs have utilized quantitative methods, specifically questionnaires, to develop epistemic profiles and analyze data in relation to another area of inquiry (e.g., Buehl & Alexander, 2005; Lohse-Bossenz et al., 2019; Markic & Eilks, 2012; Muis, 2008). Many of these studies employed different questionnaires for their purposes. For example, Tsai (2006), and van Driel et al. (2008) used a self-developed instrument, but Adams et al. (2006), Buehl and Alexander (2005), Barbera et al., (2008), Duffy et al. (2017), and Muis et al. (2019) either directly employed, modified, or fused questionnaires referenced in the field. Some of these questionnaires include the *Domain-Specific Beliefs Questionnaire* (Buehl & Alexander, 2005), the *Colorado Learning Attitudes about Science Survey* (Barbera et al., 2008), the *Epistemic Beliefs Inventory* (Duffy et al., 2017), the *Psycho-Epistemological Profile* (Muis, 2008), and the *Epistemic Emotions Scale* (Muis et al., 2019). For those who created a survey, existing surveys such as the *Maryland Physics Expectation Survey* and the *Epistemological Beliefs Assessment about Physical Science* (Adams et al., 2006; Tsai, 2006; van Driel et al., 2008) were used to develop a quantitative instrument tailored to their studies. Whether researchers chose to develop a questionnaire or utilize a previously developed instrument, these instruments all used Likert-scales as well as Cronbach's alpha as a measure of reliability.

When reporting quantitative research regarding epistemic beliefs, data has often been described using measures of central tendency with standard deviation reported (e.g., Buehl & Alexander, 2005; Duffy et al., 2017; Muis, 2008; Muis et al., 2019; Tsai, 2006; van Driel et al., 2008). Some studies have used frequency distributions to describe their findings (e.g., Buehl & Alexander, 2005; Markic & Eilks, 2012). When studies used more than one quantitative method of measurement, correlation or agreement amongst data was measured using the Pearson correlation (van Driel et al., 2008), Cohen's kappa (Buehl & Alexander, 2005), and the creation of grouping or clustering data to observe patterns (Buehl & Alexander, 2005; Markic & Eilks, 2012). Questionnaires have been used extensively in the quantitative study of epistemic beliefs (Brownlee & Schraw, 2017; Fives & Buehl, 2017) but alternatives such as quantitative analysis of interviews and images are also identified within the literature (e.g., Markic & Eilks, 2012; Muis et al., 2019). Quantitative methods, whether used within mixed methods research or on their own, have been commonly used when researching epistemic beliefs in education.

Researchers often collect and analyze quantitative data to investigate epistemic beliefs (Maggioni & Parkinson, 2008). However, recently, studies considering epistemic beliefs of teachers and their pedagogical practice have begun to incorporate qualitative approaches in their research (e.g., Brownlee & Schraw, 2017; Fives & Buehl, 2017; Larkin et al., 2019). The most common method that I identified in qualitative research of epistemic beliefs was interviewing. Participants were often interviewed using a semi-structured format, and interview data was coded (or sorted) by the researcher per the research questions being investigated (e.g., Domert et al., 2007; Edwards et al., 2017; Feucht, 2017; Hammer, 1994; Roth & Roychoudry, 2007; Tsai, 2006). As an alternative to this approach, a study by Dolphin and Tillotson (2015) used a structured and pre-defined interview protocol, the *Beliefs and Nature of Science Interview Protocol*, to investigate pre-service teachers' epistemic beliefs about science. Again, the method of interviewing was selected based on the nature of the research question.

Some studies elucidated the need to use less direct interview questions than one might find in studies outside of epistemic beliefs research (Domert et al., 2007; Hammer, 1994); indirect questions were better suited to these studies since participants found it difficult to answer direct questions about their beliefs. Correspondingly, interviewers used indirect questioning and interpreted beliefs from received responses. Since interviewers can use probing questions and observe participant behaviours, interview data adds a dimension of context and another layer of interpretation to epistemic belief research that is difficult to achieve by solely quantitative methods (Brownlee & Schraw, 2017; Fives & Buehl, 2017; Maggioni & Parkinson, 2008).

Mixed methods research has also been used to investigate epistemic beliefs. When considering epistemic beliefs about teaching and learning science with teacher candidates, Markic and Eilks (2012) used an integrative model of mixed methods research. They integrated data throughout the collection process as well as during their analysis. This interpretive research focused on coding and quantitatively analyzing student teacher drawings as well as two questionnaires about curricula and beliefs about the nature of school science. Another example of mixed methods research used to investigate epistemic beliefs is the work of Tsai (2006). Investigating teachers' scientific epistemic views and their relations to instruction in middle-school science, Tsai triangulated data from interviews, classroom observations, and a self-developed questionnaire to measure various aspects of the teaching and beliefs. He coded and placed data along a continuum of epistemic beliefs ranging from positivist to constructivist. Tsai chose specific methods to match those areas investigated using interviews to identify teachers' scientific epistemic views, classroom observations to analyze teaching practices, and a questionnaire (aligned to those questions posed in the interview) to measure students' epistemic views on science. Researchers have combined different methods when researching teachers' epistemic beliefs to explore data and situations from multiple vantage points.

3.2.2. Researching Teacher Concerns

According to Hall and Hord (1987, 2015), concerns regarding a new innovation, such as the implementation of a new curriculum document, have often been studied using one (or a combination) of three different procedures: interviews, open-ended concerns statements, and the Stages of Concern Questionnaire (SoCQ). Researchers have studied concerns using a combination of two or more of these methods (e.g., Abadie & Bista, 2018; Fischer et al., 2019; Gabby et al., 2017; Fuller, 1969; Tunks & Weller, 2009; van den Berg et al., 2000). Yet, it has also been common for studies to use only one method to analyze teacher concerns (e.g., Borgerding et al., 2013; Gudyanga & Jita, 2018; Kwok, 2014; Le Fevre, 2014; Oguoma et al., 2019; Yan & Deng, 2019). Whether researchers chose to use single or multiple methods of data collection and analysis, most studies of teacher concerns have used *a priori* dimensions from which questions were derived and/or data was coded. Most of these pre-defined dimensions are based on CBAM (specifically the stages of concern framework) as outlined by Hall and colleagues (1973) and explained in section *2.3.3. Analyzing Concerns using the Concerns Based Adoption Model* of this thesis.

Hall and Hord (1987, 2015) recommended informal interviews as one potential method of data collection to investigate teacher concerns. Specifically, Hall and Hord encouraged the use of a one-legged conference, which is similar to an informal interview beginning with an open-ended question, moving to probing questions to clarify the stages of concern from which a teacher is operating, analyzing teacher responses, and finally, attempting to address these concerns. More recent research into teacher concerns (e.g., Abadie & Bista, 2018; Borgerding et al., 2013; Fischer et al., 2019; Gabby et al., 2017) has opted to use the semi-structured interview in which open-ended prompts were prepared but the researcher was permitted to further investigate potentially interesting and relevant areas. One study, Le Fevre (2014) used informal interviews as a way of initially investigating teacher concerns but moved to using semi-structured interviews for formal data collection. Studies that have used interviews to examine teacher concerns typically discussed analyzing and coding interview data in terms of pre-determined stages (or areas) of concern. Most often, these *a priori* frameworks were based on CBAM and this allowed concerns researchers to communicate results with consistent language.

Teachers' concerns have also been investigated using open-ended concerns statements where participants wrote a description of their concerns by responding to prompts such as, "When you think about the 2017 Physics curriculum, what concerns do you have?" Responses to these prompts would be analyzed and coded per their stage of concern. Fuller (1969), whose research inspired the development of CBAM, utilized written statements to diagnose the concerns of teacher candidates. Groups were surveyed approximately every two weeks by an external researcher, and concerns classified into three categories: concerns of self, concerns about the classroom, and concerns of student learning. When using CBAM, some studies used open-ended concerns statements in addition to the Stages of Concern Questionnaire to gain an understanding of the context surrounding teacher concerns (e.g., Gabby et al., 2017; van den Berg et al., 2000; van den Berg & Ros, 1999). Occasionally, open-ended concerns methods are still used to investigate teacher concerns but their use is not as common as other methods used in recent studies; research investigating teacher concerns tends to focus on using surveys or semi-structured interviews as opposed to open-ended response approaches.

The final and most frequently used method of exploring teachers' stages of concern is the use of the Stages of Concern Questionnaire (SoCQ). The SoCQ, developed by Hall, George and Rutherford (1979) is a 35-item questionnaire using an 8-point Likert scale where teachers rate the relative truth of each statement to their current situation. Researchers typically use these ratings to interpret a teacher's 'highest' (or most strongly voiced) stage of concern. Commonly, this questionnaire has been adapted and used in studies investigating teacher concerns, particularly those applying CBAM (e.g., Charalambous & Philippou, 2010; Christou et al., 2004; Fischer et al., 2019; Gudyanga & Jita, 2019; Leung, 2008; van den Berg et al., 2000). Most studies have used Cronbach's alpha to determine the reliability of responses, as suggested by Hall et al. (1979). However, I identified three studies that did not use Cronbach's alpha (Abadie & Bista, 2018; Gabby et al., 2017; Tunks & Weller, 2009). Tunks and Weller (2009) did not discuss reliability or validity of their survey, Gabby et al. (2017) mentioned the use of triangulation to increase validity of their findings but focused on the validation of qualitative data, and Abadie & Bista (2018) referred to the SoCQ as being considered a valid and reliable instrument based on the work of other researchers. The SoCQ is the most common quantitative instrument used to determine teachers' stage of concern and the reliability of this instrument has typically been determined using Cronbach's alpha.

When using the SoCQ, analysis strategies included the use of percentiles (e.g., Abadie & Bista, 2018; Tunks & Weller, 2009), group profiles (e.g., Gabby et al., 2017; Kwok, 2014; Oguoma et al., 2019; van den Berg, 1993), percentages of respondents in each category (e.g., van den Berg et al., 2000; Tunks & Weller, 2009; van den Berg & Ros, 1999), and, most commonly, measures of central tendency with standard deviation reported (e.g., Charalambous & Philippou, 2010; Kwok, 2014; Leung, 2008; Yan & Deng, 2019). Recently, a study by Gudyanga and Jita (2019) took a different approach and focused on analyzing teachers' concerns by viewing individual teachers' SoCQ profiles as well as the average profile of an entire cohort of teachers. This analysis allowed Gudyanga and Jita to consider the SoCQ scores of individuals as they contributed to the scores of the entire group whereas other studies have typically focused on groups of teachers. Using individual teachers' SoCQ profiles provided researchers with a finer (and more contextualized) view of individuals' concerns as opposed to group studies that did not consider individual's stages of concern in favour of the average concerns.

Finally, in those studies combining more than one of the methods described (interviews, open-ended statements, or the SoCQ) to measure teacher concerns, a mixed methods approach was taken (e.g., Fischer et al., 2019; Leung (2008); Tunks & Weller, 2009). According to Johnson and Onwuegbuzie (2004), mixed methods research includes a quantitative phase and a (separate) qualitative phase. Yet, recent researchers (e.g., Bazeley, 2018a; Shannon-Baker & Edwards, 2018) have challenged this definition and described mixed methods research as any study using multiple methods of data collection and analysis (e.g., visual methods, quantitative methods, qualitative methods, etc.) to thoughtfully and purposefully analyze and mix multiple data sets. Studies using more than one method to study teachers' stages of concern, such as Charalambous and Philippou (2010), typically used qualitative methods to deeply understand teachers' concerns and confirm or disconfirm patterns found within their quantitative, SoCQ analysis. As indicated by the three different procedures offered by Hall and Hord (1987, 2015), it is possible for research investigating teacher concerns to use quantitative, qualitative, or mixed methods approaches.

Following the approaches of previous researchers in the areas of epistemic beliefs (e.g., Markic & Eilks, 2012; Tsai, 2006) and teachers' concerns (e.g., Fischer et al., 2019; Tunks & Weller, 2009), I conceptualized, planned, and commenced data collection regarding teacher concerns using a mixed methods approach.

3.3. Intended and Revised Study Design

In this section, I discuss my reasons for wanting to pursue mixed methods research as well as both strengths and criticisms of using mixed methods research. My study did not unfold as I had anticipated. In this section, I describe, in general, how the trajectory of my research evolved as a result of complications with quantitative analysis. These complications and the resulting qualitative study are both described in detail in Appendix F and section 3.4.

3.3.1. Mixed Methods Research

Much research categorizes itself as either qualitative or quantitative but there is a third approach, mixed methods, whereby a researcher utilizes both methodological approaches to view data from various perspectives (Grix, 2004; Johnson & Onwuegbuzie, 2004). Using mixed methods allows researchers to consciously employ techniques and procedures aimed at enhancing the depth and breadth of potential findings (Harwell, 2011). As previously noted, teacher concerns, as well as epistemic beliefs, have been commonly explored (and interpreted) using both qualitative (interviews and open-ended statements) and quantitative (self-report questionnaires) methods. I considered the use of mixed methods would be optimal for my research since it offered multiple vantage points from which to view the phenomena of teachers' epistemic beliefs about physics knowledge and their concerns about the 2017 Saskatchewan Physics 30 curriculum document. Mixed methods were engaged at the outset of this study with the intention of viewing trends across a large number of teachers (quantitative) from across Saskatchewan and investigating in-depth the perspectives of a few teachers (qualitative).

It has been claimed that mixed methods research draws on the strengths of both quantitative and qualitative methods while minimizing the weaknesses of each methodological approach (Blaikie, 2010; Johnson & Onwuegbuzie, 2004). Still, mixed methods research is not without its issues and criticisms. First, mixed methods research requires a significant amount of time and expertise on behalf of the researcher as they need to operate functionally in both quantitative and qualitative methodologies (Blaikie, 2010; Harwell, 2011; Creswell & Plano Clark, 2018). This was an issue for me as a new researcher; I had to commit to overcoming a steep learning curve. Throughout this study, I drew on my knowledge of mathematics and statistics, as well as the expertise of other educational researchers, to collect and analyze quantitative data. I found the qualitative findings in this study more definitive than the survey results. Analyzing my surveys proved challenging (and frustrating) and more information regarding these challenges can be read in Appendix F. Overall, the use of mixed methods for a dissertation was a significant test but one that stretched and challenged me to grow as a novice educational researcher.

Another significant criticism of mixed methodology research is the potential for mixing (or confusion) of ontological assumptions (Blaikie, 2010; Harwell, 2011). As a mixed method, interpretivist researcher I had to maintain constant awareness of my assumptions as well as my epistemology and ontology when making methodological decisions. For example, I intended to use quantitative data, but inferential analysis of this data would not have been appropriate since inferential statistics assume that inferences can be drawn to a population or make predictions from these results. Interpretivism assumes that context is integral to the data, interpretations of data, and research decisions made; for this reason, descriptive statistics were better suited to this study. I assumed a subjective reality, unique to a specific cultural and temporal context and, as such, quantitative and qualitative analyses, as well as any data mixing, needed to ensure the influence of this context was considered.

This study initially sought to use both questionnaires and interviews as data collection methods and both have issues with self-reporting (Bazeley, 2018b; Harris & Brown, 2010). This is particularly cumbersome when investigating constructs—variables that cannot be directly observed and, thus, must be inferred from measuring observable dimensions (Cheung et al, 2001). In this study, I considered teacher concerns and epistemic beliefs to be subjective constructs that require inferences from both the researcher and respondents. Additionally, participant responses within this study may have been influenced by external factors such as perceived pressure from their administration, a perceived issue with accountability, a mismatch between the construct being studied and everyday practice, and/or concerns with responding ‘correctly’ or as they feel they might be expected to respond. To address these methodological concerns, two steps were taken. First, I ensured that participants knew their responses would only be accessed by myself and they would remain anonymous in all forms of formal reporting. Second, as suggested by Guba and Lincoln (1989), member checks were conducted to ensure that my interpretations reflected the teacher’s intended sentiment. Even with these aspects in place, as an interpretivist researcher, I recognize that there is a high level of inference in this data and its analyses.

A final consideration unique to mixed methods research is the mixing of (or integrating) data (Anguerra et al., 2018; Creswell & Plano Clark, 2018). Mixed methods research is more than multi-methods and researchers need a clear idea of how the results from each method inform other aspects of the research throughout the study (Anguerra et al., 2018). I intended to integrate this data when investigating each question. For example, the quantitative data collected regarding teachers' epistemic beliefs would inform the analysis of the qualitative data by looking for confirming or disconfirming patterns. Integration of data is at the heart of mixed methods research but scholars such as Uprichard and Dawney (2019) have argued that integration of data may produce inconsistent findings. According to Mathison (1998), inconsistent findings are more likely with mixed methods research as findings from multi-method data sets can confirm or contradict results. My findings were consistent within my qualitative analysis but the quantitative analysis told an inconsistent (and somewhat incoherent) story; due to this inconsistency, my qualitative and quantitative data certainly did not mix well and, ultimately, I completed the study focused on my qualitative data. The next section describes changes made to my original research design during this study.

3.3.2. Evolution of my Research Design

I had to alter my proposed research design and follow the data as it spoke (Fielding, 2012; Uprichard & Dawney, 2019). The design of this study was initially based on what Creswell (2015) defined as a *convergent design*, where the researcher gathers and analyzes both quantitative and qualitative data before comparing findings from both data sets. The separate phases of this design were anticipated to simplify the complicated nature of mixed methodologies (Harwell, 2011). Lather (2006) argued that mixed methods studies often relegate qualitative research to 'serve' quantitative research. However, as highlighted by Harwell (2011), the convergent design uses qualitative research to enhance the depth and breadth of potential findings within quantitative data. Figure 4 shows the intended research design as planned at the start of this study with the arrows indicating the progression through the research process.

To collect quantitative data, a Likert-scale survey investigating (a) teachers' epistemic beliefs about physics knowledge and (b) their concerns regarding the 2017 Physics 30 curriculum document in Saskatchewan. In Figure 4, this represented both rectangles portraying the quantitative data collection for beliefs (top left) and concerns (top right). Grade 12 physics teachers from across Saskatchewan were invited to respond to the questionnaire asking them about their epistemic beliefs about physics knowledge and their concerns about the 2017 Physics 30 curriculum document. Teachers' epistemic beliefs about physics knowledge were surveyed using the instrument I designed for this study (Appendix B). Teachers' concerns were surveyed using the Stages of Concern questionnaire (see Appendix C). On this survey, teachers were also given the option to volunteer to be interviewed for this study.

The survey validation and quantitative data analysis for this study did not unfold as planned. For those interested, the survey validation process is described in Appendix F. In social science research, when data speaks you need to listen to what is being said (Uprichard & Dawney, 2019); quantitative results in this study were inconsistent, making the conversation between data and researcher incomprehensible. As minimal requirements for survey validation were not deemed as being met, quantitative findings were not formally included in the results of this study and I proceeded using only the qualitative data. Figure 5 shows the revised research

Figure 4

Intended Research Design

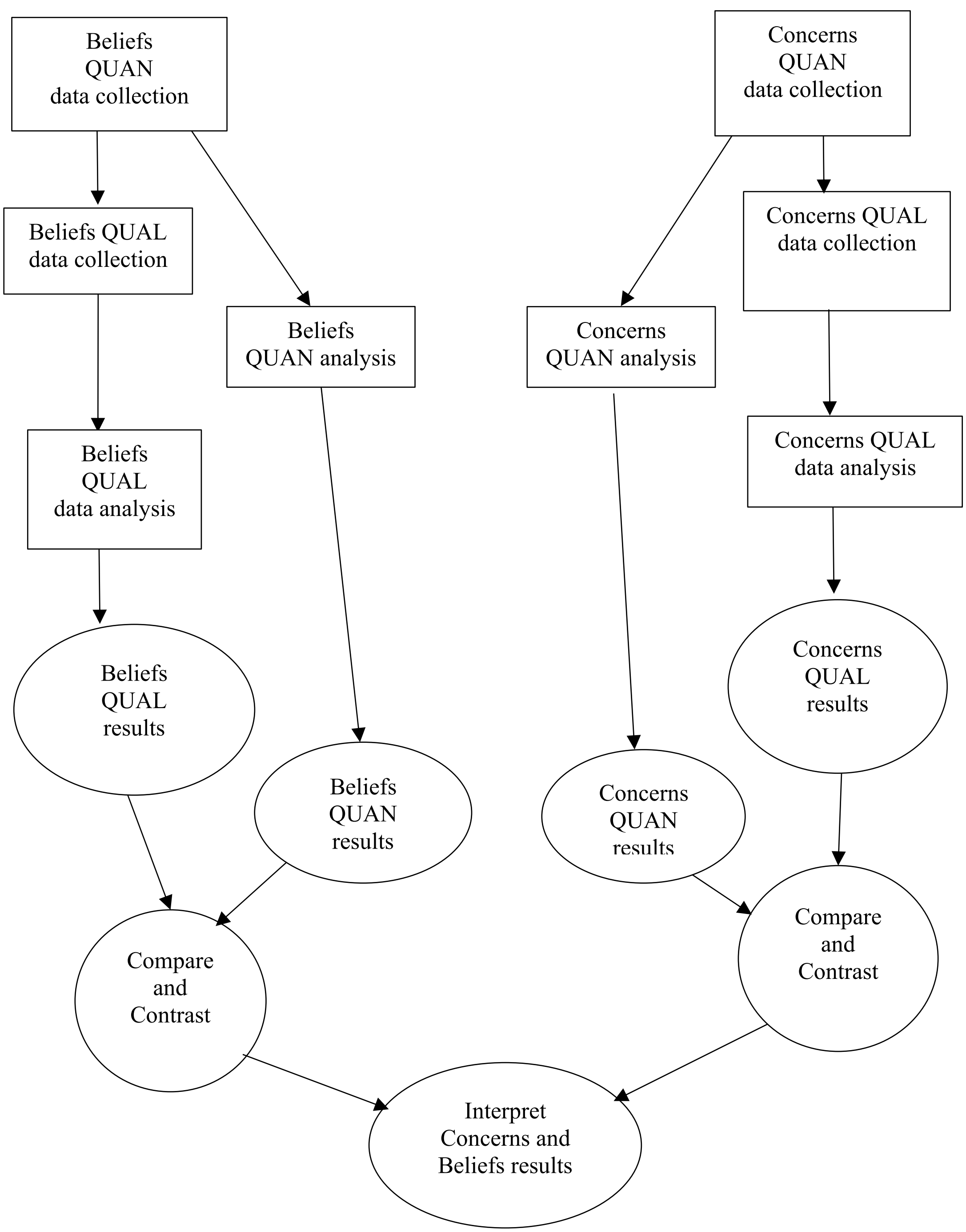
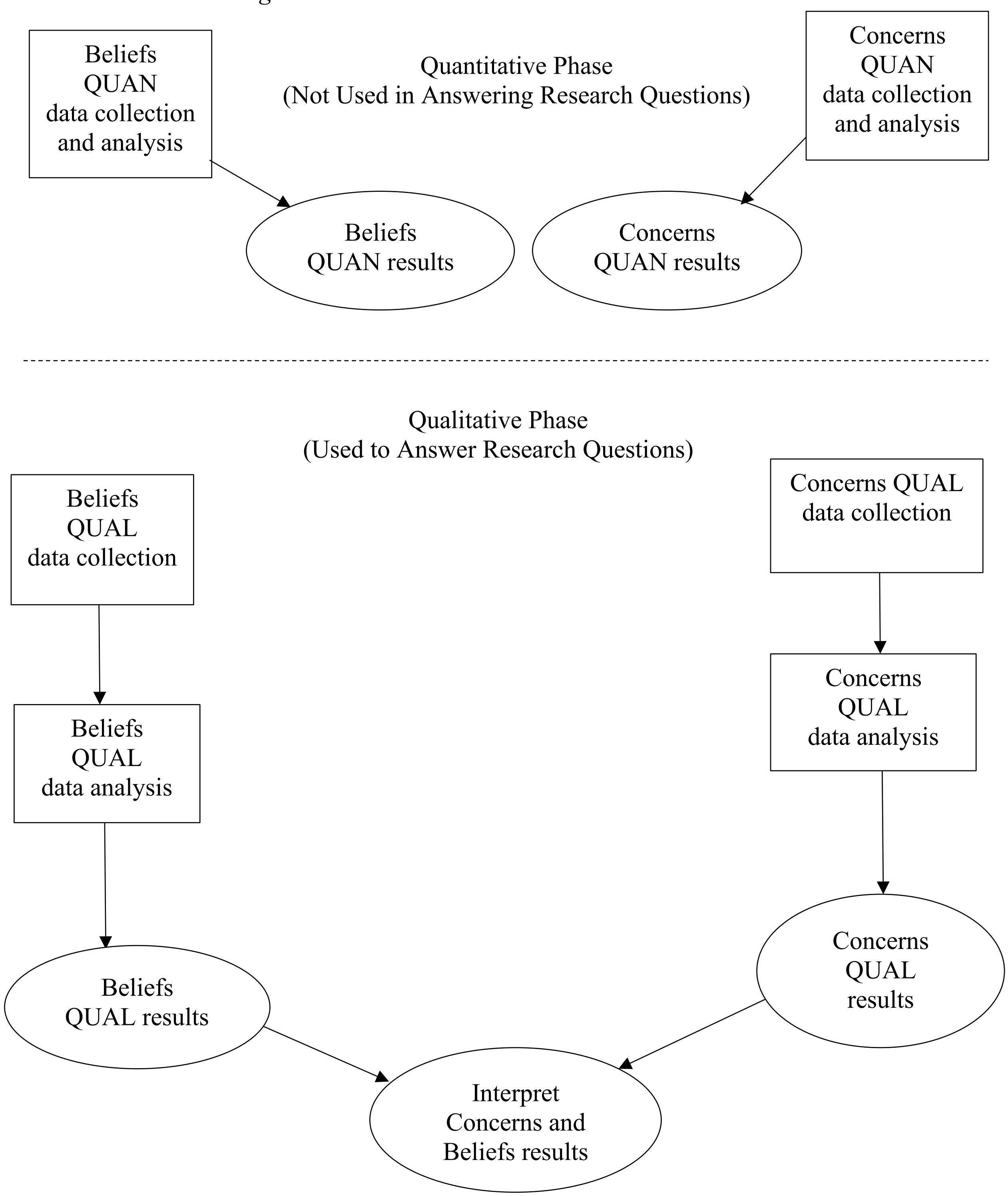


Figure 5

Revised Research Design



design where the dashed line represents the divide between the failed research quantitative portion of this study and the qualitative study. This change did not impact the proposed qualitative data collection or analysis, except for the overall mixing of data in the final step (survey data was not included).

To maintain focus on the research questions, I will now turn to describe the remainder of this study as it unfolded using only the qualitative data. Information about the failed survey validation can be found in Appendix F.

3.4. A Qualitative Query

Throughout any research study, it is important the researcher dialogue with the data, allowing it to recommend methodological decisions (Uprichard & Dawney, 2019). This section discusses the qualitative phase of this study investigating teachers' epistemic beliefs about physics knowledge and teachers' concerns regarding the 2017 Physics 30 curriculum document. As explained above, the quantitative results in this study proved to be less useful than literature had led me to anticipate they would. Despite this setback, I was still able to draw rich conclusions about teachers' epistemic beliefs about physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document through a rigorous analysis of interviews. Interview data were analyzed using thematic analysis and graphical visualizations to determine Saskatchewan teachers' epistemic beliefs about physics knowledge, their concerns about the 2017 Physics 30 curriculum document, and potential connections between these beliefs and concerns.

Following the quantitative data collection, I conducted semi-structured interviews. Beliefs were investigated during the first half of the interview in an effort to focus teachers on discussing epistemic beliefs about physics knowledge as opposed to beliefs about learning or teaching physics. Concerns regarding the 2017 Physics 30 curriculum were discussed during the second portion of each interview. Following interviews, a short summary and my initial thoughts were recorded. Data was transcribed and coded using thematic analysis for teachers' epistemic beliefs about physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document respectively. Teachers were placed along each of the four continua representing teachers' epistemic beliefs about physics knowledge. Finally, results describing teachers' epistemic beliefs about physics knowledge and their concerns about the 2017 curriculum document were mixed to search for potential connections.

3.4.1. Participant Recruitment

Interview participants were recruited through two methods: (1) those who volunteered to be a part of a follow up interview to their survey and (2) snowball sampling by asking each interviewee to pass on my contact information to any peers who might be interested in the study.

Ultimately, sixteen grade 12 physics teachers across Saskatchewan volunteered to be interviewed regarding their epistemic beliefs about physics knowledge and their concerns regarding the 2017 Physics 30 curriculum document. This number may seem small to some but, according to Brinkmann and Kvale (2015), it is common for studies using interviews to include 5 – 25 participants based on time and resources; this number falls well within this range. These teachers came from both urban (N = 9) and rural (N = 7) settings. Urban settings were defined as having the school located in a city (or within commuting distance of a city) with population over 10 000. Both female (N = 5) and male (N = 11) teachers were represented and experience teaching ranged from 6 to over 20 years.

In this study, ten teachers were accredited to teach physics in the province of Saskatchewan, meaning they had (a) taught for at least two years, (b) had taken a minimum of 21 university credit hours in academic courses in physics (or approved related courses), (c) had completed at least 3 credit hours in secondary-level curriculum science methods courses, and (d) participated in an accreditation seminar focused on appropriate assessment of student learning in physics. Accredited teachers in Saskatchewan can design the final exam for their students taking grade 12 courses; their students do not need to participate in the provincially administered Physics 30 exams.

Teachers were not directly asked about their background training in physics, as I wanted all teachers to feel comfortable discussing their beliefs even if they felt underprepared to teach the subject. I did know that both of the undergraduate education programs in Saskatchewan required a minimum of 2 courses in physics for a general science major (when this major was offered). In addition to this, teachers with physical science training (either physics or chemistry) typically took their pre-service methods course(s) together. Consequently, chemistry trained teachers have likely discussed teaching physics. Also, some years, programs at either of the universities offering secondary education degrees in Saskatchewan would combine all science majors and minors into one science methods course. Table 8 summarizes the participants, using pseudonyms, demographic information.

3.4.2. Qualitative Data Collection

I emailed those teachers volunteering to interview. Each participant and I agreed on mutual time and location for our conversation. Interviews occurred in a variety of research sites including schools, cafes, hotel lobbies, and virtual meetings. I used a hermeneutic-dialectic method, as described by Guba and Lincoln (1989), whereby new participants are interviewed until data reaches saturation, or no new information arises. As part of this hermeneutic-dialectic approach, each time a new theme emerged from interviews I incorporated probing questions to

Table 8

Participant Demographic Information

Pseudonym	Gender	Location Type	Accredited Sciences	Primary Teaching Area	Years Teaching
Alan	Male	Urban	Physics, Mathematics	Physics	6 – 10
Brad	Male	Rural	Biology	General Sciences	20 or more
Chaz	Male	Urban	Physics, Mathematics	Physics	11 – 15
Denise	Female	Rural	Physics, Chemistry	Chemistry	15 – 20
Egon	Male	Rural	None	General Sciences	6 – 10
Franz	Male	Urban	None	General Sciences	6 – 10
Gru	Male	Urban	Physics, Chemistry	Physics	11 – 15
Harley	Female	Urban	Physics, Biology, Chemistry	Chemistry	20 or more
Ian	Male	Urban	Physics, Mathematics	Physics	20 or more
Jens	Male	Rural	Chemistry	Chemistry	6 – 10
Kye	Male	Rural	Physics, Chemistry, Mathematics	Mathematics	11 – 15
Leilani	Female	Urban	Physics	Physics	11 – 15
Marcos	Male	Urban	Physics, Chemistry	Physics	20 or more
Nadia	Female	Rural	Chemistry	Physics	11 – 15
Olivia	Female	Rural	Biology, Chemistry	Biology	11 – 15
Pharris	Male	Urban	Physics, Mathematics	Physics	11 – 15

investigate this theme within subsequent interviews and returned to previously interviewed participants to collect their views on the new theme.

As is customary in research investigating teacher concerns (e.g., Borgerding et al., 2013; Le Fevre, 2014; Leung, 2008; Tunks & Weller, 2009) and epistemic belief research (e.g., Brownlee & Schraw, 2017; Domert et al., 2007; Edwards et al., 2017; Fives & Buehl, 2017; Feucht, 2017; Hammer, 1994; Roth & Roychoudry, 2007; Tsai, 2006), semi-structured interviews were used in this study. Before the initial interviews, I had planned up to 14 general questions to ask participants (see Appendix E for these questions and probing questions). Interview questions were written based on literature; for example, the question, "What are your questions with [the 2017] curriculum document?" was asked based on the definition of concerns by van denBerg and Ross (2000) who describe teachers' concerns as being identifiable, in part, by the questions raised by teachers. The first half of each interview was structured to focus on questions investigating teachers' epistemic beliefs about physics knowledge, with each question designed to interrogate one area of belief (see Table 2). Beliefs were discussed before attending to concerns in an attempt to reinforce the separation of epistemic beliefs about physics knowledge, as being investigated by this study, and beliefs about teaching and learning physics; for reasons behind this separation of epistemic beliefs please see *2.1. Epistemic Beliefs About Physics*. Typically, the discussion of teachers' epistemic beliefs about physics knowledge took approximately 30 minutes.

The second half of each interview aimed to explore teachers' concerns regarding the 2017 Physics 30 curriculum document. These questions (also available in Appendix E) were phrased to (a) investigate teachers' concerns regarding the 2017 Physics 30 curriculum document and (b) ask teachers about potential connections between their beliefs and these concerns.

Discussions regarding concerns typically took approximately 30 minutes. Participants who had completed the survey before the interview were asked to comment on findings from the survey (e.g., teachers were shown their stage of concern profile and asked whether they agreed with this output). Finally, participants were asked to summarize what they considered to be the most important aspects of our discussion that day.

Following each interview, I wrote a summary of what was discussed and a short reflection offering my interpretations from the discussion. A list of initial themes common to several interviewees and interesting questions that surfaced throughout the process was maintained. If a theme or question surfaced throughout the interview process on which an earlier participant had not commented, follow up interviews were organized to investigate these specific questions. Follow up interviews occurred virtually, either through email (written interview style) or video chat.

3.4.3. Analysis of Interview Data

Immediately following each interview, I—as the researcher and interviewer—wrote a summary of what was discussed, initial codes related to epistemic beliefs about physics knowledge and each teacher's concerns, and noted patterns (and as compared to other discussions). This summary was followed by my interpretation of an initial epistemic beliefs profile and in which stages of concern each teacher expressed concerns. This profile included which end of the continuum the teacher appeared to most strongly align with for each area of epistemic belief about physics knowledge (i.e., epistemic beliefs about the source, content, structure, and certainty of physics knowledge) and the 'strength' of this belief (i.e., how extreme teachers' epistemic beliefs lie on the continuum) as well as supporting reasons for the researcher assigning each of these codes. Noted concerns were also documented and represented under the stage of concern to by which the concern was best described. For example, if a teacher expressed concerns about having a lack of materials from which to teach, I noted that concern and listed it under stage 3, or management, concerns. Finally, while much of the literature using the stages of concern framework attempts to identify teachers' 'strongest' concerns—particularly when using quantitative measures—I opted not to use this approach when coding interviews since I could not be sure about teachers' strongest concerns nor did I ask teachers about this topic; all that I was able to interpret was whether a concern had been expressed.

Missed questions, gaps, or new topics arising from other participants were identified and, if necessary, follow up discussions were scheduled. Alan, Brad, Chaz, Denise, Egon, Harley, Ian, Kye, Olivia, and Pharris all had follow-up conversations (up to a maximum of three) where new topics (and intended meanings) were discussed. Follow up discussions were included within the original transcript as italicized texts. Transcripts and initial epistemic belief profiles (with accompanying descriptions of how these areas of epistemic beliefs about physics knowledge were defined) were sent to each participant to ensure accuracy. Franz, Gru, Jens, Leilani, Marcos and Nadia all had at least one additional conversation, most often to confirm or disconfirm my interpretations. As part of this review, participants were explicitly requested to review the epistemic belief profile and the concerns as interpreted from their interview. Teachers were asked to comment as to whether they agreed or disagreed with the researcher's interpretation. No participant requested changes to their epistemic belief profile. Only one participant requested that their concerns be rephrased and, after clarifying discussion, their suggestion was included (as agreed by participant and researcher). Each interaction with participants helped me refine my interpretations of the data to arrive at my final analysis.

3.4.3.1. Applying Thematic Analysis. After being transcribed, interview data was coded using thematic analysis, first using the epistemic beliefs about physics knowledge framework and then for teacher concerns. Since the work of Braun and Clarke (2006), thematic analysis has grown in popularity. There is some argument as to whether thematic analysis can be considered a qualitative method separable from other methodologies (Holloway & Todres, 2003; Ryan & Bernard, 2000); I agree with those authors supporting thematic analysis as a method in its own right, provided a thorough and rigorous approach is undertaken (Braun & Clarke, 2006; King, 2004; Leininger, 1992; Maguire & Delahunt, 2017; Nowell et al., 2017).

In using thematic analysis, the researcher identifies, analyzes, and reports patterns (or themes) viewed within data (Braun & Clarke, 2006; Maguire & Delahunt, 2017). According to Braun and Clarke (2006), thematic analysis involves six phases: (a) familiarize yourself with the data, (b) generate codes (if necessary) and code the data, (c) search for themes, (d) review themes, (e) define and name the themes, and (f) select exemplars representative of the theme and report. While the code and theme generation are listed in phases 2 through 4, it is also recommended that researchers using thematic analysis begin writing down initial codes and reflecting on data as early as possible (Braun & Clarke, 2006; Nowell et al., 2017; Maguire & Delahunt, 2017). Consequently, as I was interviewing participants, I recorded and noted emerging themes as they surfaced.

Thematic analysis is useful to the qualitative researcher primarily because of its flexibility (Braun & Clarke, 2006; Nowell et al., 2017; King, 2004). Thematic analysis can use pre-existing frameworks as initial codes or use inductive analysis to look for themes to be generated from data, or both (as is the case in this research). Relatively quick to learn, thematic analysis produces results that are accessible to an educated public while allowing for a thick description of the data set (Braun & Clarke, 2006; Maguire & Delahunt, 2017). Provided the researcher is rigorous in applying their measures of quality (Nowell et al., 2017), this method can generate contextually rich and accessible results.

Thematic analysis is not without disadvantages. There is a lack of literature on the use of thematic analysis, at least when compared to other qualitative methods (Nowell et al., 2017). This lack of literature is likely due to disagreement among methodologists regarding whether or not thematic analysis is indeed its own method of research and, thus, thematic analysis frequently appears in the literature under another name (Braun & Clarke, 2006). Also, the flexibility in thematic analysis can be a significant advantage to researchers but it can lead to inconsistency in data analysis (Holloway & Todres, 2003). To address this challenge, Holloway and Todres recommend researchers use a clear epistemological position or framework from which to base their analysis; for this study, pre-existing frameworks, a relativistic ontology, and subjectivist epistemology informed coding to ensure it remained consistent and coherent.

3.4.3.1.1. Analyzing Interview Data for Teachers' Epistemic Beliefs About Physics Knowledge. After transcripts and initial profiles were reviewed, coding was completed using the qualitative research software package, NVivo. I initially coded statements according to areas of epistemic beliefs about physics knowledge to which I saw them aligning (i.e., epistemic beliefs about the structure, source, certainty, or content of physics knowledge); this framework was described in section *2.1.4. Conceptual Framework for Analyzing Epistemic Beliefs about Physics Knowledge* in this thesis. This process was followed by labelling coded statements with a secondary code describing which end of the continuum the statement aligned. For example, if a statement was initially coded as "epistemic beliefs about the structure" of physics knowledge, it would then be sub-coded as either "coherent" or "isolated" representing whether the teacher's beliefs were interpreted as either communicating that physics knowledge was coherent and consisted of connected ideas or that physics knowledge was made of isolated pieces of information. All coding within this study was completed with an interpretivist paradigm in mind; I was not aiming to 'correctly' code the statements but, rather, ensure that my codes represented the teachers' intentions. When I was unsure about a participant's intended meaning of a statement, I reached out for clarification to ensure my coding properly represented their meaning. Throughout this process, I continually moved throughout the data set and emerging analysis (as recommended by Braun & Clarke, 2006), frequently revisiting codes to ensure consistency throughout the data.

For example, in reviewing Leilani's (pseudonym) transcript, statements and interactions relating to each area of epistemic beliefs about physics knowledge were coded. The interaction below was coded as relating to the certainty of knowledge in physics and later coded as supporting the epistemic belief that physics knowledge is tentative; those key words representing the link to certainty of knowledge in this interaction have been underlined.

Interviewer: Can fundamental ideas [in physics] change?

Leilani: Yeah, well, I said that really quickly because I was just thinking of when I'm teaching quantum physics and I talk about how when you first learn [the atom], it looks like the sun and you've got these little electrons orbiting, that's how we kinda... then it kind of gets... well, the orbits aren't quite in circles around the centre, and then we kind of start talking about more "what makes up a proton" and "what makes up a quark" and all that kind of stuff—fermions and all that.

I coded these statement as communicating an epistemic belief that physics knowledge is tentative because Leilani used phrases indicating that physics knowledge can and does change. Leilani communicated that fundamental ideas to physics knowledge could change. She supported this claim by discussing how we can reveal humanity's evolution of knowledge about the physics of the atomic model—as an example of a fundamental idea in physics that has changed over time.

Once interviews investigating teachers' beliefs about physics were coded, I revisited the initially generated epistemic belief profiles and member checked and compared these profiles to the coded statements for each interviewee. This comparison prompted me to change two areas of epistemic belief for participants: (a) Brad's epistemic beliefs about the source of physics knowledge changed from neutral to physics was rooted in reality and (b) Kye's epistemic beliefs about the certainty of physics knowledge changed from unchanging to tentative. Final epistemic profiles were sent to these two participants for member checking; neither participant requested changes to their epistemic profiles.

Once coding was complete and epistemic profiles member checked, I reviewed the coded statements for all teachers communicating epistemic beliefs at various points across the continua of each of the areas of beliefs about physics for emerging themes. For example, I looked at all of those statements coded as strongly communicating the epistemic belief that physics knowledge was discovered and external to the knower and identified themes best describing these statements as a whole. Themes, in this data analysis, were patterns that were discussed by multiple participants sharing common epistemic beliefs about an area of physics knowledge. For example, when considering the source of physics knowledge, it was common for teachers believing that physics knowledge was discovered from an external reality to discuss 'discovering how the world works', hence, this was deemed a theme. Themes for each area of belief were written and the list of themes reviewed for coherence in each area. Occasionally, this resulted in a theme occurring with teachers at both ends of a continuum or two themes collapsing together.

Given these themes, teachers were placed along each continuum of epistemic beliefs about physics knowledge based on those themes they most expressed. The representations of these continua showcase the range of epistemic beliefs about physics knowledge among teachers. Reasons behind the placement of teachers on these continua and themes representative of each end of each of the four continua of beliefs about physics knowledge are discussed in Chapter 5 and supported with exemplar quotations from interviews.

3.4.3.1.2. Analyzing Interview Data for Teachers' Concerns About the 2017 Saskatchewan Physics 30 Curriculum Document. Throughout the interview and transcription process, I noted concerns common to multiple participants; some examples included: concerns about teaching new content, preparing students for the final exam, a lack of materials, etc. These common concerns were used to initially code interview statements using NVivo. During coding, themes were revisited, occasionally collapsing with another theme, diffracting into multiple themes, or, in one case, being removed altogether as it had little evidence to support a robust pattern. This resulted in a total of ten identified themes, each describing a different concern held by multiple teachers.

Again, I will use Leilani's transcript to illustrate my thinking while coding teachers' concerns. The statement below was coded as *lacking confidence* because it referred to Leilani's concerns about her effectiveness as a teacher with this 2017 curriculum document. Later, this statement would be coded to the specific concern *lack of confidence in understanding of added content* because Leilani indicated that she needed to learn more about the topic before she would feel comfortable teaching the modern physics unit. Again, those key words representing the link to personal concerns in this interaction have been underlined.

Interviewer: So, <u>you were worried</u> about a few units?

Leilani: Just the modern because I had a lot to [learn about this topic] ... well, it's been forever.

Interviewer: And that was your knowledge on it, were you worried about students?

Leilani: No. I thought they would love it. I was worried about my own stuff there, not them, I knew that they would love it.

After generating and labelling themes describing the voiced concerns by interview participants, each theme was identified as existing under one of the seven stages of concern (as defined by Hall & Hord, 1987, 2015). For example, the theme describing teachers' being uncomfortable with their knowledge of the new content in the 2017 curriculum focused on teacher effectiveness to teach this new curriculum document, so it was defined as a stage 2, or personal, concern. After each theme was assigned to a stage of concern, exemplar statements and sentiments representing the theme were selected and a description of the theme written for inclusion with results.

During writing, one of the concerns raised by teachers—the content is too theoretical or not rigorous enough—originally coded as stage 2 (personal) concerns was reconsidered and re-coded as stage 4 (consequences) concerns. This revision was made because the example statements and description spoke to the student experience of the curriculum, or the consequences, as opposed to the personal effectiveness of the teacher (stage 2). This example showed how analysis in this study involved moving throughout the data, reflecting on what was happening and being open to previously unanticipated findings (King, 2004), and following the story of the thematic analysis as it unfolded (Braun & Clarke, 2006).

3.4.4. Mixing of Interview Data

The purpose of mixing the interview data in this study was to explore the question, "Were there connections between teachers' epistemic beliefs about physics knowledge and their concerns with the 2017 Saskatchewan Physics 30 curriculum document?" As this question sought to explore connections within two existing data sets using one set of cases, a pattern analysis through visual representation was used (Bazeley, 2013).

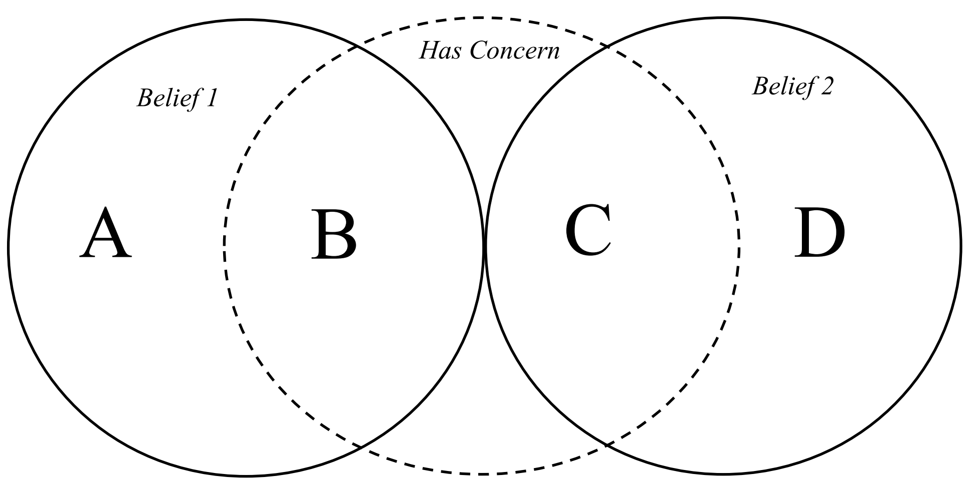
Bazeley (2018a) suggests quantifying qualitative data to complement the existing qualitative analysis. Even though I was unable to apply a mixed methods approach to my study (since I only collected data by one method), I was able to mix my two sets of qualitative results by 'quantifying' and graphically representing each of my two sets of interview results—one describing teachers' epistemic beliefs about physics knowledge and the other describing teachers' concerns regarding the 2017 Saskatchewan Physics 30 curriculum document. In this sense, I was undertaking what I am calling a *mixed analysis* approach to this research. Results from my initial, qualitative analysis of interviews were mixed using the quantitative interpretations (through counting and visual representation) of these two sets of data as described by mixed-methods researcher, Pat Bazeley (2013, 2018a).

Data display is an important consideration during qualitative analysis (Dey, 1993; Eisner, 1997; Lofland et al., 2006; Slone, 2009; Vernidelli & Scagnoli, 2013; Yin, 2011). Commonly, qualitative data is presented with written description and explanation, but there is also benefit to representing qualitative data using visual representations (Bazeley, 2013; Eisner, 1997; Sloane, 2009; Vernidelli & Scagnoli, 2013). Using visual representations in the presentation and analysis of qualitative data may provide readers with insight into the author's interpretations and thoughts (Yin, 2011). Unfortunately, despite our society using more visual forms of communication and rich history of displaying data visually in quantitative research, qualitative research has historically underused visual representation of data (Onwuegbuzie & Dickinson, 2008; Vernidelli & Scagnoli, 2013). Should the question call for it, the visual representation of data can be a powerful tool for the qualitative researcher (Eisner, 1997). As this question called for comparing two sets of data, I organized the data into two different formats allowing me to use visual representations to interpreted patterns from comparisons: Venn diagrams and matrices.

For my first visualization, I used a Venn diagram representation to consider each concern as connected to beliefs about the source and content of physics knowledge. This was done for every concern in those areas that had teachers on both sides of the continuum of an epistemic belief. A Venn diagram consists of shapes, often circles, which overlap to show possible relations among data sets (Vernidelli & Scagnoli, 2013). As shown in Figure 6, teachers could fall into one of four areas. The leftmost, solid-lined circle contains all teachers communicating the belief in one end of a belief continuum, for this example it has been called 'belief 1'. The

Figure 6

Example of a Venn Diagram Connecting Epistemic Beliefs about Physics Knowledge with an Expressed Concern



middle circle, with dashed lines, represents those teachers who reported this concern. Those teachers communicating belief 1 can either fall in area A if they do not have the concern or area B if they have this concern. Similarly, the rightmost, solid-lined circle represents teachers whose beliefs best aligned with the opposite side of the continuum to belief 1, herein called ‘belief 2’. Teachers on the other side of the continuum, communicating belief 2, can either fall in area C if they have the concern or D if they do not have the concern.

Using the Venn diagram[7] placed teachers into one of four camps, ignoring the teachers’ placement along each of the four continua of epistemic beliefs about physics knowledge. Therefore, I used another mode of visualization to seek connections between teachers’ placement along the continua of epistemic beliefs about the source and content of physics knowledge as potentially connected to their concerns about the Saskatchewan Physics 30 curriculum document.

For a more nuanced interpretation of potential connections between beliefs and concerns, I compared findings using matrices. Matrices are tables that cross-classify two variables or concepts to visualize relationships within data (Lofland et al., 2006). The use of a matrix shows potential patterns between the two constructs being investigated, in this case, epistemic beliefs about physics knowledge and teachers’ concerns about the 2017 Saskatchewan Physics 30 curriculum document. The matrix may also show that there are no connections if the teachers’ epistemic beliefs about physics knowledge and their concerns about the 2017 curriculum document showed no discernable patterns. The use of matrices in this analysis also shows how I, the researcher, viewed patterns when mixing my two sets of interview data. Matrices are the

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[7] To view a Venn diagram applying the concerns and epistemic beliefs about physics knowledge frameworks from this study, see *Figure 12. Venn Representation of Teachers’ Epistemic Beliefs about the Source of Physics Knowledge and Lack of Understanding the Content new to Physics 30*. Figures 13 – 19 also feature Venn Representations of teachers’ epistemic beliefs about physics knowledge and their concerns.

most commonly used data display in qualitative research (Vernidelli & Scagnoli, 2013) and they are an efficient way to look for patterns across multiple cases (Bazeley, 2013). The matrix provided an effective representation with which to search for patterns across multiple stages of concern and varied positions across the continua of epistemic beliefs about physics knowledge.

The choice of data display should be based on the reasons a researcher wants to investigate potential patterns (Bazeley, 2013). As I intended to view teachers' epistemic beliefs about physics knowledge (using their placement along a continuum) and what concerns might connect to these beliefs, a matrix showing both of these elements was needed. Matrices were used to compare teachers' epistemic beliefs about physics knowledge and their specific concerns regarding the 2017 Saskatchewan Physics 30 curriculum document. Matrices were created using the continua of epistemic beliefs about physics knowledge—generated through the analysis of the epistemic beliefs about physics interviews—as a horizontal axis and teachers' concerns expressed about the 2017 Saskatchewan Physics 30 curriculum document as a vertical axis. Teachers were then placed in the positions that matched their expressed beliefs and concerns. An example of these matrices[8] is shown in Table 9.

In Table 9, three fictional teachers are represented; I used pseudonyms in the actual analysis. Along the vertical axis, the concerns of each teacher can be read and, horizontally, teachers are placed along the continuum of epistemic beliefs about physics knowledge being investigated. An example of the concerns, listed as concern X, Y, W, and Z might be "concerns about teaching new content," or "concerns about variation in Physics 30 courses across

[8] To view a matrix applying the concerns and epistemic beliefs about physics knowledge frameworks from this study, see *Table 11. Visualizing Teachers' Epistemic Beliefs about the Certainty of Physics Knowledge and their Concerns.* Tables 12 - 14 also feature matrices representing teachers' epistemic beliefs about physics knowledge and their concerns.

Table 9

Example of Comparison of a Continuum of Teachers' Epistemic Beliefs About Physics Knowledge and their Concerns

	Belief 1			*Belief 2*
Concern W				
Concern X	Teacher 1		Teacher 3	
Concern Y		Teacher 2		
Concern Z			Teacher 3	

Saskatchewan.” In Table 9 teacher 1 only reported ‘concern X’ and was placed near the extreme end of belief 1, teacher 2 only reported ‘concern Y’ and was placed as communicating belief 1 but closer to neutral, and teacher 3 reported ‘concerns X and Z’ and was placed as expressing belief 2 but near neutral. In this example, no teacher communicated ‘concern W’. This type of chart was used to interpret potential connections by looking for patterns—such as clusters of teachers with similar beliefs and concerns—and gaps where teachers with certain beliefs did not report concerns.

Mixing of this data was visualized using matrices and Venn diagrams. After visualizing the data, I investigated themes among the statements given by teachers contributing to (and/or absent from) each pattern. From this thematic analysis, I discerned whether the pattern regarding this concern could be considered to be connected to their epistemic beliefs about physics knowledge or if the result may have been convoluted by some other factor. I viewed this as an important step since, while visualization in qualitative data analysis can tell a researcher much about the patterns in the data (Bazeley, 2013; Vernidelli & Scagnoli, 2013), qualitative data tells us a story under these patterns; it is this story that I aimed to provide in my analysis of the mixed interview data. Using these methods, I present research through visualization and thorough description in the results section to explore each of my proposed research questions (as outlined in section *1.3. Research Questions* in this thesis).

3.5. Quality in Qualitative Research

Positivist research has long accepted reliability, validity, generalizability, and objectivity as criteria against which to judge the quality of research (Daniel & Onwuegbuzie, 2002; Guba & Lincoln, 1989; Onwuegbuzie & Leech, 2007). These criteria, concerned with the production of consistent results, arriving at the correct answer, generalizing results to a population, and remaining objective, are inappropriate alone for judging the quality of interpretivist research. The interpretivist researcher does not seek to find a correct answer, nor do they expect results to be viewed objectively without the context in which they are being examined. They seek to understand questions within a specific context, as it is relevant to the participants and themselves. Interpretivist research cannot be generalized beyond its understood context and, thus, the interpretivist researcher would not expect the same study at a different time or place to produce consistent results. As this study operated within an interpretivist paradigm, and those areas often used to judge positivist research are not appropriate, this section outlines the assurance of quality in this study.

To address the inadequacy of the positivist criteria, Guba and Lincoln (1989) provide what they call "trustworthiness criteria" (p. 233). These trustworthiness criteria are useful to any qualitative researcher seeking to ensure the acceptability and usefulness of their research (Nowell et al., 2017). The criteria of credibility, transferability, dependability, and conformability parallel approximately the positivist criteria often used and mean to "resolve the quality issue for constructivism" (Guba & Lincoln, 1994, p. 114). These trustworthiness criteria are commonly used in interpretivist research and discussed frequently by methodologists (e.g., Creswell, 2009; Daniel & Onwuegbuzie, 2002; Guba & Lincoln, 1994; Nowell et al., 2017; Onweugbuzie & Leech, 2005). The following sections describe the trustworthiness criteria as they were applied throughout this study.

3.5.1. Credibility

Credibility reflects characteristics of internal validity, how well a study establishes 'truth' or measures what it was intended to measure (Guba & Lincoln, 1989; Shenton, 2004). However, as interpretivism does not operate on a single reality or truth, the concept of validity is difficult to apply. Credibility, or the consideration of the congruencies between the realities constructed by participants and the reality constructed by the researcher (Guba & Lincoln, 1989; Shenton, 2004), fulfilled the criterion of validity.

A key method to ensure the realities constructed by participants and the representations of these realities written by the researcher are indeed congruent is through member checking (Guba & Lincoln, 1989). Member checking entails the researcher ensuring that the participants' realities are appropriately and correctly represented by informing the participants of interpretations being made and checking to see that these accurately represent participants' intended views (Nowell et al., 2017). Throughout this research, each participant was offered the opportunity to member check transcriptions, initial coding, and their interpreted epistemic belief profiles and stages of concern. Those participants who answered follow up questions after they had member checked the original transcript were given the chance to check updated transcripts, coding, and interpreted belief profiles and stages of concern.

A second method used to ensure credibility was the checking of my progressive subjectivity. This technique allows researchers to check the privilege they give to their own constructions (Guba & Lincoln, 1989). As interpretivist research cannot be value-free, I used this technique to reflect on my expectations throughout the study. Through reflexive journaling (as suggested by Nowell et al., 2017), I maintained a record of what I expected to find as well as developing constructions and ideas that I expected to see throughout the research process. I was able to reference these records to ensure that I was not privileging my expectations and, indeed, 'listening' to the data throughout the study. To portray consequences of my progressive subjectivity processes, I have included several findings that contradicted what I had expected to find in this study in Chapter 4.

Third, I sought credibility by engaging in persistent observation and triangulation. According to Guba and Lincoln (1989), sufficient observation is vital to qualitative studies to add depth to the research. Persistent observation entails reading and rereading the data, revisiting and revising codes, and studying data until the intended depth of insight is attained (Korstjens & Moser, 2018). This study was limited to 16 participants, but this was enough to see saturation in both expressed beliefs and concerns. I noticed saturation beginning to occur in some themes (e.g., concerns about course variation in Physics 30 classrooms across Saskatchewan, physics content was tentative and subject to change, and concerns about how other teachers were teaching the 2017 Physics 30 curriculum document) as early as the sixth interview. With each added interview, I reviewed conversations with participants who had raised similar ideas. I viewed and reviewed the data during the analysis and writing of this study as prolonged engagement promotes persistent observation (Nowell et al., 2017). This persistent observation enabled me to look for confirmatory, contradictory, or inconsistent patterns within the data and interpretation, ensuring a focus on making sense of all aspects of the data instead of privileging those I found relevant.

Through persistent observation and the use of multiple methods of analysis, I was able to triangulate across participants and themes (Daniel & Onwuegbuzie, 2002; Shenton, 2004). According to Denzin (2015), researchers can use four different types of triangulation: (a) data, (b) investigator, (c) theory, and (d) methodological triangulation. In this study, I used both data and methodological triangulation. Data triangulation involves using multiple participants, searching for saturation, and spending time with the data; this was achieved through persistent observation. Methodological triangulation involves using more than one method to observe a phenomenon (Denzin, 2015). In this study, methodological triangulation was used by comparing qualitative coding with visualizations of data. For example, once teachers were placed along a continuum of epistemic beliefs about physics knowledge, I revisited their coded statements to check for consistency. As described, if these methods produced inconsistent results, I returned to the participant to determine the most accurate interpretation. This triangulation and persistent observation forced me, as the researcher, to be transparent in my interpretations, further ensuring the credibility of this study.

Finally, seeking and using negative cases allowed me to again check that I was not privileging data following certain trends nor was I ignoring those that did not follow this pattern. Negative cases are cases that do not follow the predominant patterns and trends emerging from the data (Daniel & Onwuegbuzie, 2002; Guba & Lincoln, 1989). The negative case is not a result of contradictions, representing patterns conflicting with those seen in another data set or from analysis. Instead, they represent those cases that appear to be anomalous to trends emerging from the data (Brodsky, 2008; Daniel & Onwuegbuzie, 2002). The argumentation and discussion of negative cases helps protect against researcher biases while contributing to the strengthening of findings (Brodsky, 2008). An example of a negative case included within this study is the discussion regarding Kye's agreement with teachers believing physics knowledge was invented by humans regarding the increase of theoretical content despite believing that physics knowledge exists in an external reality himself; for more on this see *4.3.1.7. Stage 4 (consequence) concern, The content is too theoretical (or not rigorous enough).*

3.5.2. Transferability

Roughly related to external validity, transferability deals with the issue of generalizing results from an interpretivist study (Guba & Lincoln, 1989). Unlike positivist studies, which promote generalizing results to describe a population from a studied sample, context, the researcher, and participants heavily influence interpretivist studies. Ensuring transferability through thick description of the research context (temporal, location, context, and culture), assumptions made, and phenomena gives other researchers a chance to compare any results of this study to similar findings and studies (Nowell et al., 2017). Another suggestion for ensuring transferability is to use the visual display of information as this better shows how another researcher might use this research approach in another context by showcasing a researcher's thinking process (Sloane, 2009). In this dissertation, through thick description, contextual information, and visual displays, I aimed to provide as complete a view as possible of the collected data and analysis "in order to facilitate transferability judgements on part of others who may wish to apply the study to their own situations" (Guba & Lincoln, 1989, p. 242).

Aligning with transferability, the data collected in this study offer a description of the existing stages of concern and epistemic beliefs shown by certain Saskatchewan Physics 30 teachers during spring 2018. It would be inappropriate to make overgeneralized statements regarding this population or any population that might be seen as similar (Cohen & Manion, 1994), especially given the sampling issues in this study. The *Tri-Council Policy Statement,* *Ethical Conduct for Research Involving* Humans (TCPS, 2014) supports this claim as it explains qualitative research findings, and knowledge, as interpretive and dependent on context. In recognition of this claim, a reflective approach—searching for findings and those contextual factors informing those findings—was stressed throughout this study. Findings from this study are contextual to the participants at the time of their participation.

3.5.3. Dependability

Intended to ensure the integrity of the data, dependability is the constructivist researcher's approach to ensuring the "consistency of evidence" (Daniel & Onwuegbuzie, 2002, p. 8). Daniel and Onwuegbuzie also suggest dependability be addressed through triangulation, negative case analysis (both of which were discussed in *3.5.1. Credibility*), and ensuring adequate evidence for methodological decisions and interpretations. To increase dependability, researchers must be transparent regarding the research process and show a logical, traceable, and clearly documented research process (Guba & Lincoln, 1989; Nowell et al., 2017). To achieve this, throughout this study, along with triangulation, negative case analysis, and explorations of inconsistencies in data, a record of research decisions made was maintained in the form of a researcher's journal and this information was used to write the data collection and analysis sections above.

3.5.4. Confirmability

Parallel to objectivity, confirmability addresses how well results represent the context and participants in a study (Guba & Lincoln, 1989). The interpretivist researcher cannot be objective; to achieve confirmability, as suggested by Guba and Lincoln, I maintained a means of tracking data to their sources and a record of reasons behind interpretations (to showcase interpretation logic). Also, as suggested by Koch (1994) and Nowell and colleagues (2017), a thorough account of theoretical, methodological, and analytical choices have been discussed in sections *3.1.* and *3.4.* as well as Appendix F. Additionally, visual representations of my data analysis, showing my methodological moves in data analysis, have been included to make it easier for readers to see this information, confirm my findings, or alternatively interpret results (Sloane, 2009). Methodological decisions were included to provide a transparent account of the research steps taken throughout the study, to make certain assertions made in this study are traceable to collected data.

3.6. Ensuring Ethical Research

No research is risk free, but the ethical researcher seeks to pursue knowledge through research while maintaining respect for and protecting research participants (TCPS, 2014). This section briefly outlines some of the practices observed to ensure this study proceeded ethically.

3.6.1. Participant Selection

According to the TCPS (2014), participant selection is to be made based on inclusion criteria which are justified only by the research question. Therefore, participant selection was made fairly and equitably. All Saskatchewan teachers with exposure to the 2017 Physics 30 curriculum document were eligible for participation in this research and any teacher volunteering to be part of this research was included in the phase of data collection in which they were interested (qualitative, quantitative, or both).

3.6.2. Informed Consent

The TCPS (2014) heavily stresses that any research with human subjects requires "free, informed, and ongoing consent" (p. 7). I ensured informed consent by describing the scope and sequence of the study and the expectations for each participant. Participants were provided with a letter of information to initiate any new research relationship. This letter made clear that participation in this study was on an entirely voluntary basis and the participant was able to withdraw from the study at any time. It was indicated that—should participants choose to withdraw—there would be no adverse repercussions to their employment. Should a participant have chosen to withdraw, their collected data would have been maintained within the study unless they request otherwise; this information was also included within the letter. Throughout the study, participants were fully informed of the study and given the opportunity to voluntarily participate in this study without any form of coercion.

All participants were informed of the study in writing and voluntary consent was sought with each data collection method. For example, within the online questionnaires, a question indicating participant consent for the use of data was included. For the interview process, participants were required to sign a consent form before the interview. On this form, participants also had the opportunity to indicate if they did not wish to be audio recorded. Participants were informed these audio recordings were also voluntary, and would only be used to create transcriptions of the conversation to better ensure accurate and detailed data analysis. One participant declined audio recording, and, in this interview, notes were taken throughout the discussion and emailed as a transcription for member checking.

3.6.3. Ethics in Interviewing

As a researcher and participant enter an interview, the researcher must recognize the complexities and ethical considerations undertaken in this situation. First, I needed to be aware of confidential and potentially sensitive topics to be covered (Brenner, 2006; Brinkmann & Kvale, 2015). While one can never be entirely sure about what topics will be sensitive to participants, I was prepared for these situations to arise. “[Researchers] should aim to protect the welfare of participants, and, in some circumstances, to promote that welfare in view of any foreseeable risks associated with the research" (TCPS, 2014, p. 8). While interviewing, I was careful to ensure my participants were not exposed to unnecessary risks or harm. This research was relatively low risk, but there was the potential for teachers to feel threatened if they felt that their beliefs were being questioned. Thankfully, this was not the case during any interview. Still, to be thorough, every attempt was made to adequately prepare participants for the questions and areas to be addressed within the research as well as ensuring participants knew that all data was to be made confidential using pseudonyms in all forms of reporting.

3.6.4. Ethical Treatment of Data and Confidentiality

As indicated by TCPS (2014), participant data and information must be kept confidential. Data was stored ethically and reported anonymously. All data collected electronically (including audio recordings and transcripts) was only accessible through password encryption to ensure data was kept secure and confidential. Any data collected by hardcopy, as well as any data printed for analysis, was stored within a locked cabinet at the University of Alberta, only accessible to the researcher by key. All data was kept securely for the duration of the study, after study completion, and will be destroyed after five years as approved by the University of Alberta Research Ethics Board.

Along with security measures to maintain the confidentiality of data, it is also important data is presented ethically. To achieve this, data has been anonymized throughout all forms of reporting. All participant data and quotations have been represented under a pseudonym. Background information of participants was kept to a minimum in reporting to avoid the identification of any participant. Participants who requested updates have been made aware of the results found by the researcher. Finally, participants were made aware that the final dissemination of data may include academic presentations and written publications.

3.7. Methodology Summary

This chapter opened with a description of the interpretivist paradigm including framing both the relativist ontology and subjectivist epistemology underpinning this research. The historical contexts of research investigating teachers' epistemic beliefs and research exploring teachers' concerns were then detailed. This study sought to identify and understand (as much as possible) potential connections between teachers' epistemic beliefs about physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document; it was not my intention to attempt an explanation for these connections or search for causality. Findings from this research present my understanding of these phenomena, informed and guided by teacher participants, in a specific context, Saskatchewan in the spring of 2018. Findings and interpretations were limited to those opinions and viewpoints expressed by my participant group. As interpretivist research, this study offers further description to the literature researching teachers' epistemic beliefs, teachers' concerns, physics teachers, and Canadian (and Saskatchewan) science education.

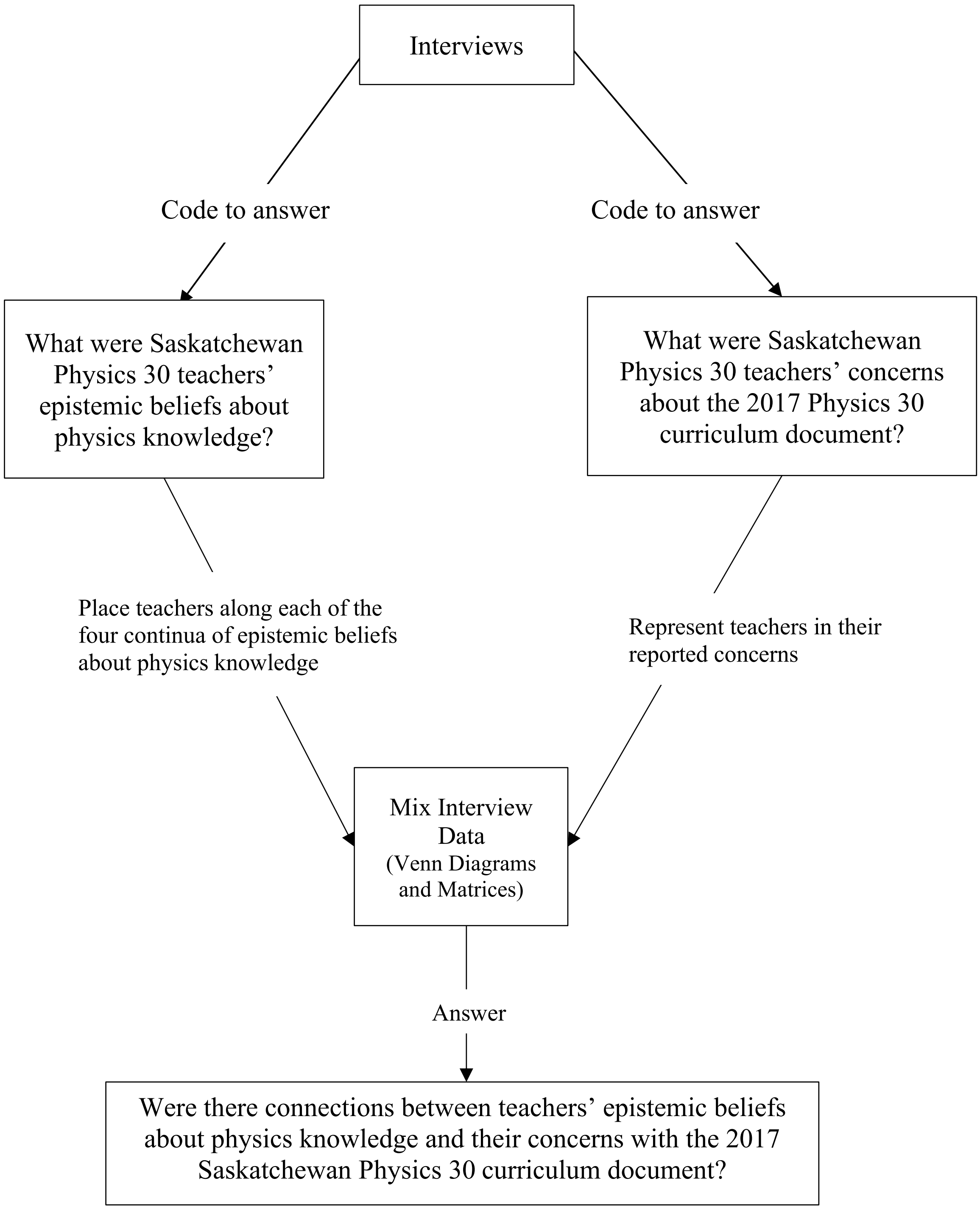
In this chapter, I provided information on the planned use of mixed methods and presented my reasons for pursuing this methodology. Both the intended research design (Figure 4) and the revised research design (Figure 5) from this study were provided. The processes used to collect and analyze data, including the issues with quantitative data in this study, were outlined. Quantitative surveys were found to be less reliable or valid than had been expected (see Appendix F); consequently, as described in *3.4. A Qualitative Query,* this study focused on thematic analysis and visual representation as means to interpret interview data.

In the end, this study was not a mixed methods study since only one type of data was analyzed. In *3.4.4. Mixing of Interview Data*, I suggested calling this research mixed analysis because different analysis approaches (e.g., thematic analysis and visual representation) were used to answer two of my research questions: “What were Saskatchewan Physics 30 teachers’ epistemic beliefs about physics knowledge?” and “What were Saskatchewan Physics 30 teachers’ concerns about the 2017 Physics 30 curriculum document?” Results from these analyses were then mixed using Venn diagrams and matrices. I described this study as mixed analysis research since I integrated multiple sets of results—from considering the interviews through two different frameworks—and listened as they spoke to each other as suggested by Shannon-Baker and Edwards (2018).

Following the description of the research design, measures used to assure quality in this interpretivist research were discussed. Each of Guba and Lincoln’s (1989) trustworthiness criteria (credibility, transferability, dependability and confirmability) was briefly defined and measures taken within this study to meet each criterion described. Finally, the procedures used to ensure ethical research were explained. A visualization of the conducted analysis for this study and the connection to the proposed research questions can be seen in Figure 7 (which is another way of viewing Figure 5 from below the dashed line).

Figure 7

Visualizing the Analysis of this Study



CHAPTER 4: RESULTS

In this chapter, I describe the findings for each of the three research questions. First, I delineate the epistemic beliefs about physics knowledge reported by the teachers in this study. Second, the teachers' concerns regarding the 2017 Physics 30 curriculum document in Saskatchewan are described. Finally, the analysis of the teacher concerns interview data and the analysis of teachers' epistemic beliefs about physics knowledge interview data are compared. This comparison was made to explore potential connections between teachers' epistemic beliefs about physics knowledge and their concerns in adopting the content within the 2017 Saskatchewan Physics 30 curriculum document. Findings for this comparison are presented both visually and using qualitative description to provide the reader with further insight into the analysis process informing these results.

4.1. What were Saskatchewan Physics 30 Teachers' Epistemic Beliefs About Physics Knowledge?

Teachers in this study were interested in discussing their epistemic beliefs about physics knowledge and felt this was a valuable experience. As one example, Brad, a non-accredited physics teacher in a rural school, stated,

> It felt good to me to [...] tell you about what physics means; those sorts of bigger questions and things [...] you think about them but the hard part is that you rarely get someone to talk with about it because nobody knows it [...] I'd like to get together to talk physics with other teachers but don't have anyone here.

In general, participants' epistemic beliefs were similar regarding both the structure and the certainty of physics knowledge. Most (13 of 16) teachers communicated that the source of physics knowledge was external to the knower (i.e., physics was discovered) while only 3 participants expressed the belief that physics knowledge was invented by humans. Eight participants described the content of physics knowledge as primarily mathematical, and eight participants reported the belief that the content of physics knowledge was conceptual and qualitative.

In the next sections of this chapter, teachers are placed along each of the four continua of epistemic beliefs about physics knowledge as I have interpreted their placements. I acknowledge that individual placements along each continuum could vary depending on the researcher. To minimize this variance, I have grouped participants as opposed to placing them in specific positions. These groupings and placements are the result of my interpretation and are meant to represent the teachers' epistemic beliefs about each area of physics knowledge.

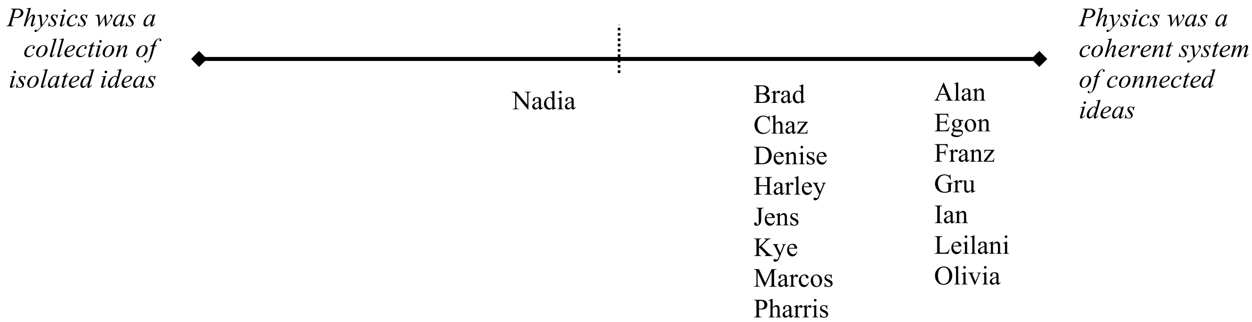
4.1.1. Epistemic Beliefs About the Structure of Physics Knowledge

Most (15 of 16) participants expressed the belief that physics knowledge was at least somewhat coherent and connected. The lack of an accepted grand unifying theory of physics was identified as a limiting factor to complete coherence of physics knowledge. Teachers also indicated that physics taught in schools does not represent this coherence and connectedness appropriately.

As displayed in Figure 8, teachers reported, to varying degrees, that physics knowledge was coherent and connected. Teachers strongly believing that physics knowledge was coherent (depicted as being part of the rightmost grouping on Figure 8) commonly supported their view by suggesting that physics ideas were connected through concepts such as motion (Chaz, Egon and Olivia) or through mathematics (Franz). For instance, Brad, a non-accredited physics teacher with more than 20 years of teaching experience, said, "if you had equations that describe the positions of electrons and if you had Einstein's gravitational field equations you could probably

Figure 8

Continuum of Epistemic Beliefs about the Structure of Physics Knowledge with Teachers Placed



explain everything that happens. I think there's some very fundamental things that will explain a lot." Brad used the word "fundamental" to describe those ideas (or "things") that connect multiple areas of physics; to him, one could use these ideas to explain most physical interactions.

Three teachers (Chaz, Egon, and Olivia) discussed the coherence of physics knowledge using the concept of motion. Egon, another non-accredited teacher in rural Saskatchewan, echoed this viewpoint by claiming, "fundamental ideas are those that tie [concepts in physics] together," and he went on to say "if there was one core idea that held all of physics together, I would say it would probably be motion." This centrality of the concept of motion was also reported by two accredited teachers in urban centers, Chaz who said, "motion is an overall tying theme in physics" and Leilani who stated, "chemistry is about interactions and physics was about the motion of those interactions." These physics teachers saw physics knowledge as connected with cross-cutting or 'fundamental' ideas, commonly citing 'motion' as one such idea.

As one caveat to physics knowledge being constructed of coherent ideas, participants referred to the ongoing search for a grand unified theory. "Can [ideas in physics] all be connected? I think they can, but I don't think we're there yet […] we still need to make those connections" mentioned Denise, an accredited teacher with approximately 15 years of experience teaching physics. Her sentiments were echoed by Jens, a non-accredited physics teacher in rural

Saskatchewan, who, when asked whether we can connect all the ideas in physics said, “well, they’re trying, they haven’t succeeded yet, right?” Similar statements to these two were also made by accredited teachers Kye, Harley, and Chaz. To these teachers, physics knowledge was coherent and connected, but not completely so. However, these teachers were hopeful that one day these final connections would be made.

Unlike her colleagues, as shown in Figure 8, Nadia believed that physics concepts cannot always be connected. Nadia, a non-accredited physics teacher working in rural Saskatchewan, indicated that some aspects of physics were connected, such as forces and motion or mirrors and lenses, but other aspects were separable, such as forces and lenses. As an example, when first asked whether physics ideas could be connected, Nadia said,

> There’s some [ideas in physics] that are very related and some that you can totally separate. [In] Physics 20 we talk about mirrors and lenses, [and] it’s very different from forces and motion [in Physics 30] so I think there’s some [ideas] that can be separated.

For the past thirty years, the Saskatchewan physics curriculum has taught topics such as ‘mirrors and lenses’ in grade 11 (or Physics 20) and topics related to ‘forces and motion’ in grade 12 (or Physics 30). Saskatchewan’s ‘school’ physics separated these ideas. When probed for clarification regarding the separation of physics ideas, Nadia continued to return to the separable aspects of physics as the content in the school curriculum. She went on to say, “I think physics is so broad; that there’s so many ideas. I feel like every *unit* [emphasis added] there is almost different things.” This comment differed from those teachers discussing physics as a coherent system of ideas, who referred to physics as a field of knowledge.

It may be that teachers understand the coherence of the discipline of physics but the curriculum does not necessarily showcase any such coherence and, consequently, many students see physics knowledge as isolated pieces of information. For example, Gru, an accredited physics teacher with approximately 15 years of teaching experience, said,

> For a lot of [students] it's like, "OK, so we were doing this unit and now we're doing this unit and what do these units have to do with each other?" and I'm like, "Well, there's these things called fundamental forces and… and really, the electromagnetism and the strong nuclear force and the weak nuclear force are really the electroweak force, but…" and they're like "What?" and I'm like, [to the students] "Don't worry about it."

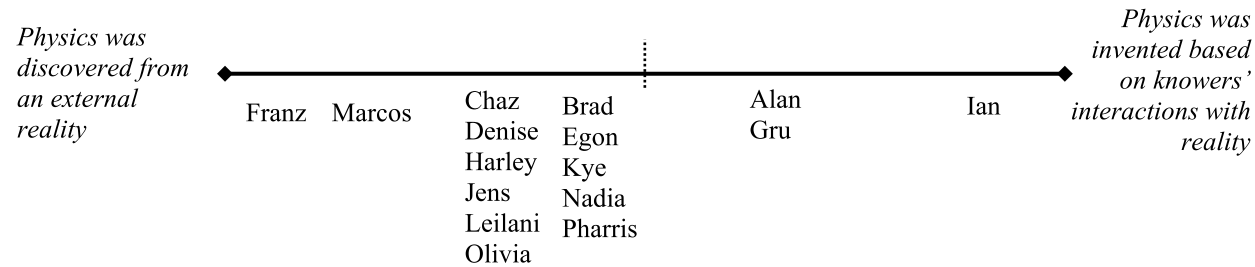
As evidenced by Nadia's response and Gru's anecdote, the compartmentalized high school physics course structures presented physics knowledge as a collection of isolated ideas. Even teachers (such as Gru) indicating that physics knowledge was constructed of coherent and connected ideas, taught school physics as separate 'units' of concepts. As Gru's anecdote highlights, teachers may have believed that physics knowledge was coherent but did not enact this epistemic belief when teaching 'school' physics.

4.1.2. Epistemic Beliefs about the Source of Physics Knowledge

Throughout the interviews, most (13 of 16) teachers were placed along the continuum of epistemic beliefs about the source of physics knowledge (shown in Figure 9) as believing that physics knowledge was predetermined and waiting to be discovered, that is, physics knowledge existed beyond human control. These teachers were placed toward the left side of the continuum represented in Figure 9. For example, Marcos, a physics teacher for over 20 years, was placed nearer the left side of this continuum as a result of claims such as, "it seems like the physical laws, scientific theories, and constants were set at the big bang and then we are just discovering those things that were set. I don't think we're inventing [those things]." His beliefs were also consistent with those of Franz who said, "you don't invent how the world works, you discover

Figure 9

Continuum of Epistemic Beliefs about the Source of Physics Knowledge with Teachers Placed



how the world works." Both of these teachers communicated the belief that physics knowledge was waiting to be discovered from an external reality. When placing these teachers on the continuum, Franz was placed further on the extreme than Marcos since Marcos used some hesitant language (e.g., "it seems like,") whereas Franz did not. These two teachers strongly represented the epistemic belief that physics knowledge was discovered.

Those participants less firmly believing that physics knowledge was discovered were placed just to the left of neutral on this continuum because they reported sentiments that physics knowledge was discovered from an external reality but they also considered physics knowledge to have been explained by people, i.e., physicists. For example, when asked whether she felt physics knowledge was discovered or invented, Harley initially answered, "Hmm… both." Later in the conversation, Harley committed to one side of the continuum more than the other, saying, "I think that [physics is] discovered because it's there we just have to figure out what it is." Pharris reported similar beliefs; to him, "we discovered many things that always existed, but we are also inventing it as we go." Ultimately, Pharris was placed relatively centrally on the continuum of epistemic beliefs about the source of physics, but slightly on the side representing those believing that physics knowledge was discovered. This interpretation was a result of statements such as, "since old theories get replaced by new ones there needs to be a certain level of invention," which indicated that he saw physics knowledge as discovered but that there was some degree of invention to physics knowledge. Those participants grouped on the less extreme side of believing that physics knowledge was discovered argued for physics knowledge as representing an external reality, but they also discussed physics knowledge as being invented by humanity. Ultimately, these teachers leaned toward one end of this continuum more than the other.

On the other end of this continuum, 3 of 16 teachers expressed the belief that physics knowledge was invented. According to Ian, an urban physics teacher with over 20 years in the classroom, "physics is invented because it's a human endeavour […] we choose to see specific things, we choose to see certain things because we have a particular paradigm, so we are looking for stuff that supports that." To support this claim, Ian cited the works of Kuhn (1996). As another example of this anthropic orientation, Egon, a science and history teacher in rural Saskatchewan, said, "we have all these laws and rules that we've made to make sense of the things that we've encountered and they're there from the confines of our culture, our understanding of it, and our understanding of the universe." Both Egon and Ian described physics knowledge as the explanation of the physical world; in contrast, those teachers who believed that physics knowledge existed and was waiting to be discovered tended to describe physics as the behaviour of, and interactions within, the physical world.

Ian was deemed as believing physics was invented by humanity more so than both Gru and Egon because both Egon and Gru, like those deemed less resolute in their epistemic beliefs that physics knowledge preexisted in reality, described this human-constructed knowledge as based on a shared sense of (external) reality. For these three participants, physics knowledge was written by humans, as claimed by scientists such as Neils Bohr (Gregory, 1988). Those teachers reporting the epistemic belief that physics knowledge was invented by humanity described physics as explanations written by humans from within particular contexts.

For Brad, Harley, Leilani, and Kye, the source of physics knowledge was a difficult area to discuss and they were often inconsistent and uncertain regarding their beliefs. It was common for these participants to claim they believed physics knowledge was discovered but then make statements describing physics knowledge as coming from human explanation. For example, Leilani, an accredited physics teacher in an urban center, claimed, “physics is discovered—I mean—we didn’t invent magnetism,” and then later said, “I think [physics principles] existed and we’re trying to come up with an understanding of it,” and finally questioned herself by saying, “is that inventing something?” It appeared that Leilani was not sure about her beliefs about the source of physics knowledge but, in her mind, physics was discovered, at least in in this instance, first. A similar scenario occurred with Harley who said, “I think that [physics knowledge] is discovered because, in my opinion, I think it’s there [and] we just have to figure out what it is” but later said, “[physics], as a discipline, it’s a human construct. Even our explanations are human constructs of a world that exists beyond us… we’re just coming up with something that explains what we observe.” This statement highlights the lack of certainty some teachers expressed between describing physics knowledge as socially-constructed (i.e., invented), focusing on the explanation of phenomena, and physics knowledge as external to the knower (i.e., discovered), described as the phenomena themselves; both Leilani and Harley were unsure as to whether physics knowledge existed within the phenomena (it is discovered) or the explanation of the phenomena (it is invented).

4.1.3. Epistemic Beliefs About the Certainty of Physics Knowledge

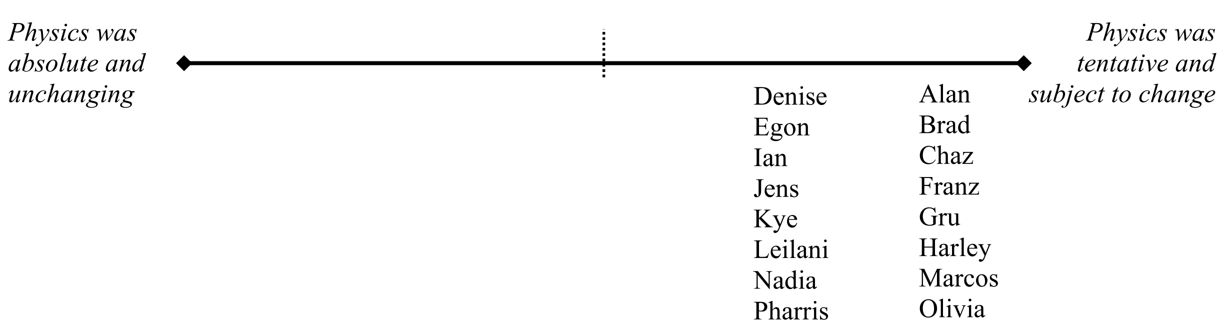
As shown in Figure 10, all participants consistently expressed the belief that physics knowledge was tentative and likely to change. Of those teachers who expressed this belief, the strongest believers (furthest right on the continuum) voiced the opinion that physics was not only likely to change, but such change was something expected within the science community. For example, Olivia, a physics teacher who had previously worked as a field scientist, believed that physics knowledge was tentative and subject to change and claimed that the idea that science (particularly physics) is unchanging was a common misconception.

> Everyone [sees] science as almost like a bible that gives standards and tells us how it will always be and it never changes. People have this conception about science and when things do change or when we're wrong about something – "WHAT?!" – and the scientists are like (*sic*), "Yeah? So? We knew things could change."

To Olivia, experts (i.e., scientists) understood that science was likely to change, whereas the public may not share the same view. Those teachers who were placed at the extreme end of this continuum communicated that "science is very dynamic and it changes" (Marcos) and that physics was not only likely to change but that physics "needs a shakeup—something has to

Figure 10

Continuum of Epistemic Beliefs about the Certainty of Physics Knowledge with Teachers Placed



change" (Brad). These teachers voicing that physics knowledge was tentative, like physicists (Redish et al., 1998), described the field of physics as something that regularly changes.

Those teachers placed nearer the middle of this continuum communicated the belief that physics knowledge was likely to change but they were reluctant to agree that the 'fundamental' ideas of physics could change. For example, when asked if she thought physics knowledge could change, Leilani replied, "I think [it] could change; like, the standard model could change," but when asked about another aspect of physics such as whether Newton's Laws could change, her reply was "no. Well, [*laughs]* I think no." Egon concurred with these teachers, saying, "some concepts of physics (Newton's laws and things like that) are almost a cornerstone and I couldn't foresee them [changing]." Teachers in this group claimed that 'newer ideas' in physics could change but those ideas that were foundational to physics knowledge were unlikely to change. Kye, an accredited physics teacher working in a rural setting, explained that whether physics knowledge was tentative depended on the physics concepts being considered;

> Some [concepts] are just so... like, gravity is gravity. Gravity on Earth is not going to change unless the mass of the Earth changes (which hopefully won't happen). But I think when we start getting to the edges of physics with stuff like subatomic particles and trying to figure out some of the bigger questions of the universe, then, yeah, that will change (Kye).

To Kye, the "edges of physics"—those ideas newer to the field—were likely to change but he had difficulty agreeing that those ideas 'fundamental' to physics knowledge were likely to change.

Still, all teachers in this study voiced the opinion that physics knowledge was able to change. Jens, a male teacher with little formal physics training, claimed that science teachers had to agree with the fact that physics can change;

> I mean, how can one be certain that everything we think we know about the physical world is correct? A lot of it isn't quite perfectly proven yet […] So, I would absolutely say things would have to change a little bit as we go forward. (Jens)

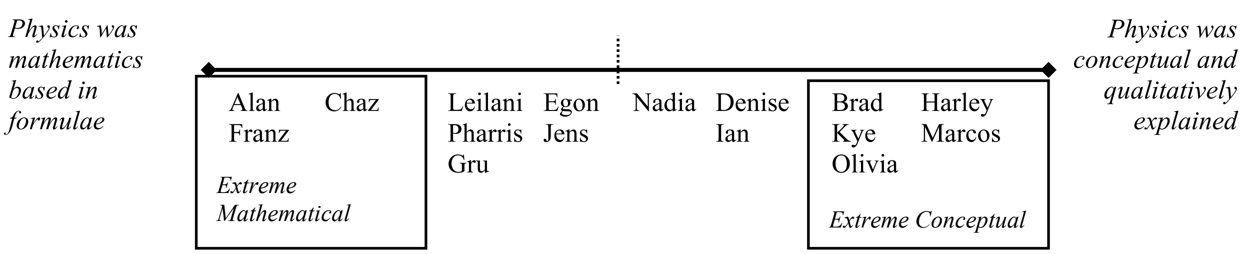
When discussing their epistemic beliefs about the certainty of physics knowledge, teachers communicating the belief that physics knowledge was likely to change, but some teachers explained that 'fundamental' ideas, such as Newton's Laws, in physics were unlikely to change.

4.1.4. Epistemic Beliefs About the Content of Physics Knowledge

Eight teachers believed the content of physics knowledge was mathematical and eight teachers believed that physics knowledge was conceptual/qualitative. Teachers' epistemic beliefs varied across the continuum, as depicted in Figure 11. Teachers' epistemic beliefs about the content of physics knowledge were characterized as either tending towards mathematics (based in formulae) or conceptual (and qualitatively explained). Since teachers were distributed throughout this continuum, unlike the larger groupings seen in previous continua, those groups

Figure 11

Continuum of Epistemic Beliefs about the Content of Physics Knowledge with Teachers Placed



that I considered to represent more extreme beliefs on either end of this continuum have been shown using labelled boxes.

All teachers used the terms "mathematics" and "physics" to represent separate disciplines. Mathematics often referred to the use and manipulation of equations, quantification, and the data used for observation. Qualitative physics, on the other hand, was often described using terms such as "concepts"[9] (Brad, Denise, Egon, Franz, Harley, Jens, Kye, Marcos, Nadia, and Olivia) or "the theory"[10] (Alan, Kye, Marcos, and Olivia). Mathematics, to participants, served a purpose but could be separated from physics. Chaz summarized the sentiments expressed by most interviewees when he said, "math is a tool for physics; it's not a way of interpreting the world, it's a way that physics uses for understanding how the world works around us." Teachers frequently referred to mathematics as a tool or language used within physics to explain physical phenomena, but that mathematics was not the same as physics.

Teachers placed on the extreme end the continuum representing the belief that physics knowledge was conceptual and qualitative identified mathematics as a tool, not necessarily how we know in physics. These teachers included Harley, Brad, Kye, Marcos, and Olivia. Each claimed that it was possible to understand physics without mathematics. Harley, for example, explained that she often taught physics to her students without mathematics; "you can teach physics like a math teacher or you can teach physics like a science teacher. They can be

[9] Examples of statements describing qualitative physics as "concepts" include: "I teach [some] **concepts** separate from mathematics," (Egon), "I only teach **concepts** right now [not mathematics yet]," (Harley), or "thinking about things like magnetics and magnetic fields, you don't really need to know math to know how a magnetic field, it's just a **concept**" (Jens).

[10] Examples of statements describing qualitative physics as "the theory" include: "I teach **the theory** and where those ideas came from, but this is a small part of my class as compared to the mathematics" (Alan), "At a very basic level you need to be able to either do the mathematics or understand **the theory**, preferably both," (Kye), "I try to have **the theory** in the true and false or multiple choice so that's the physics. Then the applied stuff with the formulas," (Marcos).

separated because math is knowing what to do whereas physics tells us why we do it," (Harley). To Harley, most concepts in physics could be explained without mathematics. Brad and Marcos corroborated Harley's claim that mathematics was a tool that described 'what to do' in physics; "mathematics is a tool for us science people," (Marcos).

Teachers at the 'extreme conceptual' end of the continuum representing teachers' epistemic beliefs about the content of physics knowledge discussed mathematics as a tool for use in physics, not as a language in physics. When asked whether she felt mathematics was the language of physics, Harley made a face of disgust. Mathematics, to these teachers, supported knowing in physics but was not necessarily physics knowledge; "[the math] gives a better understanding of the physics of it, but it's not required to understand [a concept]," (Kye). Conceptual physics knowledge, to these teachers, was a deeper way of knowing physics; "I think when you get to upper level then things become more conceptual in physics," (Marcos). As was claimed by many teachers, physics and mathematics were separate, but those teachers most strongly voicing the epistemic belief that physics knowledge was conceptual claimed that mathematics was a tool that described what to do with an understanding of physics, which these teachers described as knowing why something happened.

Denise, Ian, and Nadia believed that physics knowledge was conceptual and qualitative but were less convinced mathematics could be removed from physics. These three teachers were placed to the right of centre on Figure 11. These teachers also believed that knowing mathematics was integral to knowing physics but that physics knowledge was conceptual and qualitative. As Ian explained,

> You don't need to understand math to know physics because any child knows physics. As soon as you learn how to catch, you can solve a very complicated differential equation in real time. So, you know physics without knowing the math.

To Ian, physics knowledge was conceptual and qualitative at its core. However, Ian went on to explain how physics required mathematics,

> Can you describe the physics? Can you describe the understandings? Can you make predictions without the math? That is a different story. I suspect that you need some significant mathematical tools to be able to do more than just blow hot air about physics.

These teachers suggested that a person can claim to know physics without understanding mathematics, but that knowing mathematics was required for a thorough understanding of physics. "[When] physicists want to communicate a concept […] using a tool like math is very helpful," said Denise who went on to describe mathematics as the language of physics. Identifying mathematics as a language, as opposed to a tool, indicated that these teachers believed that physics knowledge was conceptual but also relied on knowing mathematics. "It is about doing the math but I think you have to understand why […] you need to understand a lot more about how physics works," (Nadia). To these teachers, physics knowledge was certainly conceptual, but knowing mathematics was also necessary for knowing in physics.

Egon, Leilani, Jens, Pharris, and Gru believed that physics knowledge was rooted in mathematics but also somewhat conceptual. These five teachers were placed to the left of centre on Figure 11. These teachers described mathematics as necessary proof for a deep understanding of conceptual ideas in physics.

> I also think [physics knowledge was in] the mathematics like going down an inclined plane how mass is irrelevant. So, we have that concept and we talk about dropping a

> feather and a penny and air resistance and stuff but then we'll show it doing a demo and then we'll prove it mathematically—how the masses cancel out. (Leilani)

While ideas in physics can be considered concepts (such as mass is irrelevant in acceleration due to gravity), Leilani suggests that it is with the mathematics that these concepts are proven. These teachers communicated that mathematics provides the evidence necessary for physics knowledge and credibility to the conceptual side of physics. As another example, Egon claimed that physics knowledge might be expressed qualitatively but that mathematics was required for a deeper understanding of the more complex ideas in physics; "the more you understand math, the more you will understand the physics," (Egon). These teachers conveyed that mathematics was necessary to prove, or give credibility to, an individual's physics knowledge but also expressed that the conceptual aspect of physics was "intertwined with mathematics" (Egon). To these teachers, these two aspects—mathematics and conceptual physics—were difficult to separate. Therefore, these teachers were labelled as believing that physics knowledge was mathematically oriented, but they still recognized that conceptual knowledge was part of physics.

The fourth and final 'category' of teachers' epistemic beliefs about the content of physics knowledge consisted of those teachers represented at the extreme left of this continuum who communicated the belief that mathematics was at the core of physics knowledge. To Alan, Chaz, and Franz, mathematics was the evidence of knowledge in physics and the discipline of physics was defined by its problem-solving focus. Franz claimed,

> Math binds the world. Math is the way you explain everything because math is data— to me anyway […] physics is what—you know—the way you explain physics is math […] math is what helps you justify data, justify your explanations and all that is through math.

To Franz, mathematics served as the evidence of knowledge in physics; it was through data (synonymous with mathematics for Franz) that physics knowledge was defined. Mathematics was essential to physics knowledge; "one of the fundamental ideas [of physics] are [*sic*] a really strong understanding of math, trig, and algebra," (Alan). For Alan, physics knowledge was proven with "quantifiable data." Finally, Chaz was grouped with these teachers but slightly more towards the middle of the continuum representing teachers' epistemic beliefs about the content of physics knowledge since he described mathematics as central to knowing in physics but not as *the way* we know in physics. According to Chaz,

> Do you need to know math to know physics? I can definitely see people saying "No, you don't" but I just think that the connection is so much greater when you know math—you know? […] To me math makes it so... the relationships are just so much more clear [*sic*] if you have that understanding of math. That's what I try to stress in my class. […] My emphasis is definitely on math [...] I think it is a core foundation of physics.

Chaz believed that mathematics was central to physics knowledge since knowing the 'relationships' and the mathematical side of physics provided an individual with a better (he used the term "clearer") understanding of physics. This response implied that he presumed a person might be able to acquire some understanding of physics without mathematics but Chaz challenged the idea of entirely conceptual knowing claiming that the content of physics was primarily mathematically-oriented.

4.1.5. Summarizing Teachers' Epistemic Beliefs about Physics Knowledge in this Study

Teachers were placed along each of the continua of epistemic beliefs about physics knowledge based on the degree to which they communicated sentiments reflecting each extreme. These placements were based on my interpretations and given clarification via member checks with participants. Participants primarily concurred regarding the structure and the certainty of physics knowledge. There was some variation in teachers' epistemic beliefs regarding the source of physics knowledge. Finally, the widest distribution of teachers was identified along the continuum of epistemic beliefs about the content of physics knowledge.

Almost all (15 of 16) participants expressed the belief that physics knowledge was coherent and connected with some variation in the strength of their beliefs. The exception to this finding was Nadia who primarily discussed her beliefs in terms of the physics taught in schools. Nadia described physics knowledge as consisting of isolated pieces of information. A frequently raised caveat to believing that physics knowledge was part of a coherent and connected system was that physicists were still searching for a grand unified theory. Still, all participants believed that physics knowledge was tentative and likely to change with the frequent stipulation that the "fundamental" concepts of physics (e.g., Newton's Laws) were unlikely to change.

Teachers predominantly believed that physics knowledge was discovered—that it was preexistent in a reality beyond the knower—with only three teachers expressing the belief that physics was invented by humans. However, it should be noted that some teachers communicated inconsistencies in their expressed epistemic beliefs about the source of physics knowledge and statements made throughout the interview. Epistemic beliefs about the source of physics knowledge was the most difficult of the four areas of epistemic beliefs about physics knowledge for participants to discuss.

Finally, teachers were distributed across the continuum representing teachers' epistemic beliefs about the content of physics knowledge. Teachers ranged from strongly believing that the content of physics knowledge was conceptual and qualitative to strongly believing that the content of physics knowledge was rooted in mathematics. There was the widest variation in epistemic beliefs across this continuum. Still, all teachers did gravitate to one side or the other of this continuum.

4.2. What were Saskatchewan Physics 30 Teachers' Concerns about the 2017 Physics 30 Curriculum Document?

Saskatchewan Physics 30 teachers were eager to discuss their concerns, worries, questions, and anxieties regarding the 2017 Saskatchewan Physics 30 curriculum document. As the coding for concerns was seeking to answer the question "What were Saskatchewan Physics 30 teachers' concerns about the 2017 Physics 30 curriculum document?" all concerns were considered, not only those thought to be connected to teachers' epistemic beliefs about physics knowledge. This means that the reader will find concerns discussed throughout this study which were raised by teachers but may not have been connected to their epistemic beliefs about physics knowledge. After coding and reviewing interview data, it was noted that the participants expressed concerns ranging between stages two (personal) and five (collaboration) of the Stages of Concern framework (as defined by Hall & Hord, 2015 and described in section *2.3.3. Analyzing Concerns using the Concerns Based Adoption Model* of this thesis). The strongest sentiments were expressed in stages three (management) and four (consequence); it was in these two stages that participants often voiced the most frustration and they would cycle back to these concerns throughout our discussions regarding the 2017 Physics 30 curriculum document.

4.2.1. Stage 2 (Personal) Concerns

Hall and Hord (1987, 2015) define stage two concerns as those worries and questions a teacher has about their effectiveness in delivering a new innovation, such as a curriculum document. Teachers' lack of confidence in understanding newly added topics in the 2017 curriculum was the most common theme among those teachers' expressing personal concerns.

Non-accredited teachers also voiced concerns about preparing students to write the Physics 30 provincial exam. Note that concerns about how students would understand the content in the 2017 curriculum did not fall under this stage of the stages of concern but, instead, are represented in stage four (concerns regarding impact and consequences).

4.2.1.1. Lack of Confidence in Understanding the Content new to Physics 30. Nine of sixteen teachers expressed some lack of confidence in understanding content in the 2017 Saskatchewan Physics 30 curriculum document that was not part of the 1992 document. These included non-accredited teachers Brad, Egon, Jens, Nadia, Olivia and accredited teachers Denise, Harley, Kye, and Leilani. Concerns about understanding content either referred to knowing specific topics in the curriculum, such as ‘electricity and magnetism’ (housed in the unit on fields) or ‘modern physics’, or topics teachers considered controversial in the field of physics such as dark matter. Teachers reported that they did not know the content in these newly introduced topics well enough to teach them and expressed personal concerns about whether they could teach this content effectively. The outcomes regarding fields (including electricity and magnetism) and modern physics topics were added to the 2017 Physics 30 curriculum document whereas the other content topics (forces, motion, and conservation laws) were all derived from the 1992 curriculum document. No teacher expressed concern regarding those topics found in the 1992 curriculum document.

As an example of the concerns mentioned regarding a lack of confidence in their understanding of added content, Jens, a physics teacher of approximately 8 years who holds bachelor’s degrees in chemistry and education said, “I was definitely apprehensive about teaching the modern physics because, with a limited physics background, I didn’t really know a ton about it.” Similarly, Harley, a seasoned accredited physics teacher, said she was still concerned about teaching fields "because [she didn't] know a lot about it and there aren't very many resources about it." Kye summarized teachers' sentiments nicely; "I have to make sure my understanding is good and then [I can] bring it from where it is in my head to [my students]." Teachers who were concerned about teaching unfamiliar content discussed a desire to ensure they truly understood these ideas before they could be effective in teaching these ideas to their students.

Egon, a non-accredited physics teacher of approximately 10 years, was concerned about teaching content that was uncertain (or yet to be accepted as physics canon). He worried that the field of physics did not yet understand—or agree upon—these concepts; hence, he questioned whether the added content that was yet to be understood should be taught. Egon specifically expressed concerns regarding teaching students about dark matter;

> I was like, "Hold on. We're not sure about dark matter, so… yeah?" […] in some ways it's great that we're on the cutting edge about teaching [students] about all the theories but the ones that we're still theorizing about, maybe leave that as the optional extra for the A-team (the students who want to learn more).

To Egon, teaching students about ideas that he considered as still being theorized was questionable; he was concerned about being able to teach these ideas to the 'typical' student in Physics 30. Egon had reservations when it came to teaching content that was yet to be fully understood by the field of physics to students.

4.2.1.2. Teacher Effectiveness in Ensuring Success on the Provincial Exam. Brad, Nadia, and Olivia—all of whose students had to write the Physics 30 provincial exam—raised concerns regarding their effectiveness in preparing students to write this exam. Most often, these concerns highlighted the tension non-accredited teachers felt between teaching from a more ‘open’ curriculum document and preparing students to write a ‘closed’ provincial exam.

Mirroring a study completed with Scottish science teachers (Wallace & Priestly, 2017), teachers in this study were frustrated by having to reconcile the new, more ‘open’ curriculum document with preparing students for a standardized exam. When it came to provincial exam preparation, teachers were irritated with the 2017 curriculum largely because of the outcome and indicator format. “The whole idea of having outcomes and indicators is really useless to me because of the [provincial exam],” (Franz). The 2017 document was designed to encourage exploration with required outcomes supported by indicators which may be used to meet each outcome, increasing Physics 30 teachers’ freedom when designing their courses. However, non-accredited teachers communicated that they were unable to benefit from this freedom. This suggests a lack of equity between teachers at a provincial level based on those credentials defined by the Ministry of Education as being worthy of not having one’s teaching and students’ learning monitored by a provincially controlled final exam.

For accredited teachers, this meant more freedom in how and what they wanted to teach in their course; for example, Harley expressed feeling “guilty” because, as an accredited teacher, she was able to spend less time on some outcomes to go deeper into the newly included modern outcomes whereas non-accredited teachers had to ‘cover’ everything in the curriculum document during the semester. For those teachers whose students had to write a provincial exam, this open format was frustrating because they felt they had to cover all indicators anyway; “[the provincial exam] just restricts me […] ultimately, I have to teach the indicators because that’s what’s going to be evaluated,” said Franz. While the 2017 curriculum document was meant to provide teachers with more freedom in designing their Physics 30 course, non-accredited teachers found the outcome-indicator structure complicated their course planning.

To add to this, some teachers felt unable to divine what indicators would be assessed by the provincial exam. For example, Brad said, “How are we going to know if we just have indicators what they’re gonna (*sic*) need to know for their final exam since teachers are supposed to be [teaching] just some indicators.” This uncertainty was less prevalent with the 1992 curriculum document which, according to Brad, “had 285 things on a checklist, [that he] could photo blast those on the first day … [and he and his students could] tick them off and make sure [he] did all of them [to prepare students].” The open format of the 2017 curriculum document concerned some non-accredited teachers because they felt they had to discern what would be assessed on the provincial exam, a process they were less worried about with the 1992 document.

Non-accredited teachers were concerned about their effectiveness in teaching this course because they felt restricted to preparing students for the provincial exam. Olivia stated, “If I wasn’t bound by a [provincial exam], it’s a good curriculum, I enjoy it.” Nadia, like others with this concern, expressed that she would teach a very different course if she were accredited; she would spend more time exploring aspects of the curriculum that she felt were interesting instead of finding those that could be measured on a multiple-choice exam. Nadia went on to say, “I mean, we’re supposed to differentiate our teaching, but we’ve standardized our tests.” Teachers were being told to teach those indicators that they felt met the outcome (including the possibility of creating indicators). Non-accredited teachers expressed concerns about being bound to preparing students for standardized exams and this conflicted with the messages of exploration and autonomy implied in the outcome-indicator format of the 2017 Saskatchewan Physics 30 curriculum document.

4.2.2. Stage 3 (Management) Concerns

Stage 3 concerns, as defined by Hall and Hord (1987, 2015) are those worries and questions a teacher has regarding the management, logistics, and implementation of an innovation. In this study, these concerns related to teachers' desires for practical suggestions regarding the logistics of implementation. Teachers with management concerns were concerned about a lack of resources or instruction for teachers' on how to teach using this document. Teachers also expressed management concerns regarding the amount of time they had to cover the content in this curriculum document. As a former high school teacher who has experienced curricular changes, I was not surprised to see these logistics-based concerns. We, as teachers, are often left to worry about whether we are 'properly' teaching the content and it is in resources that we, or at least I, find assurance that we are 'correctly' teaching what is expected. Teachers with management concerns were often concerned about how to properly undertake the planning and teaching of the 2017 Saskatchewan Physics 30 curriculum document.

4.2.2.1. Lack of Instructions and Resources. Teachers expressed concern regarding a lack of instructions about how to teach the content included in the 2017 curriculum document and a lack of resources with which to teach the content. All of the non-accredited teachers in this study (Brad, Egon, Franz, Jens, Nadia, and Olivia) expressed this concern. Accredited teachers Gru and Pharris also expressed concerns about a lack of instructions and resources to assist teachers in implementing the 2017 Physics 30 curriculum document. Additionally, teachers were concerned about a lack of direction about how to allocate their time throughout their Physics 30 course. Teachers with these concerns were also concerned about how to teach the content in the 2017 Physics 30 curriculum document.

Teachers questioned how they were to teach this document and (for those with management concerns) this was often connected to a lack of available resources. Concerns of this nature ranged from teachers wanting a specific layout of what to teach (e.g., Nadia stating "whenever they bring in a new curriculum, they should give [teachers] a binder and say this is basically it") to the problem of teachers having to use too many resources (e.g., Olivia "used lots of different textbooks […] to cover every topic that's covered in the curriculum because there's no perfect textbook"). Egon added, "there is less supporting material [with this new curriculum]," as he did not know of any central website or textbook and he went on to say, "[this is] especially [true] for that electricity and fields unit." Teachers were frustrated with the lack of identified, content-focused resources to supporting the 2017 curriculum document, especially with those topics in the 2017 curriculum document that were not part of the required content in the 1992 curriculum document (e.g., fields and modern physics).

Teachers were frustrated and understood the lack of a formal textbook but still wanted direction on where to begin; as Nadia said,

> Nobody's gonna build a textbook [for] the Saskatchewan curriculum because we're just not that big, right? So, I think you have to pull from a bunch of different sources and make it your own. But if [the Ministry of Education] gave us anything, any kind of starting place, that would be beneficial.

For some, this starting place could be found in the content that overlapped with the old document. According to Pharris, any new curriculum "come[s] with minimal resources and a lot of overlap [so I] usually reorganize the content I already have and then supplement with new stuff." As some outcomes were similar to those that existed in the 1992 document, recyclable material was the easiest place for many to start; "aside from the new things they added on, I still teach my old curriculum," (Alan). Teachers' wants and needs regarding resources varied, but it was clear that teachers wanted common resources to assist them with teaching the content in the 2017 Saskatchewan Physics 30 curriculum document.

Furthermore, two teachers, Jens and Gru, voiced concerns about a lack of direction regarding the time that should be spent on each topic (or outcome). Gru said, "[as] with all the new sciences, I miss the recommended time to spend on stuff." The 1992 Physics 30 curriculum document indicated specific hour counts to be dedicated to each unit (e.g., 20 – 30 hours to teach the unit about electric circuits, 8 – 10 hours for the unit about work and energy, etc.) whereas the 2017 document did not have such recommendations. As Jens said, there were topics in this curriculum that "you could design an entire course on […] so it's kind of hard to know how to allocate your time." Gru "like[d] that [the Ministry of Education] treated [teachers] as professionals […] able to make their own decisions but," he reported that "having some criteria to make those decisions upon [would be] useful." As a result, Gru—even though he was accredited to teach physics in Saskatchewan—reverse engineered time allocations based on the number of questions asked of each outcome on the provincial (and prototype provincial) exams. Both Jens and Gru reported concerns about the lack of instruction given on time allocation to units with the new curriculum document.

4.2.2.2. There is Too Much Content to Cover. "They took out electric circuits and added relativity and quantum mechanics, plus made magnetism mandatory. So, they took out 5 days of my lessons and added on 12. Great. How am I going to do this?" (Alan). As exemplified by Alan's comment, some teachers expressed that there was just too much content to possibly 'cover' in one semester of physics within this document; how could they teach all of this content in one course? Alan, Chaz, Franz, Harley, and Olivia all reported these concerns.

One potential reason for this concern, reported by Olivia, was that each outcome was supported by a lot of indicators and some of these indicators, such as velocity and vectors, could take quite a bit of time to teach on their own.

> There's lots of indicators in each outcome and […] one of the indicators deals with velocity and vectors and that's huge on its own; it can be massive. So, there's the one indicator in there that lists all the different equations and that alone is huge—to go through and show how to use and when to use those equations and in what circumstances you use those equations—that is massive on its own. (Olivia)

As she was not accredited in physics, Olivia felt responsible for covering all of the potential indicators that could be assessed on the provincial exam; "the thing is because I've written questions for the biology [provincial exam], so I know now, after that experience, that I have to make sure every indicator is covered," (Olivia). She felt that she could meet all of the outcomes throughout a term, but Olivia reported concerns about covering all of the content (meaning indicators) in Physics 30 in one term. The document was structured in such a way that teachers only needed to cover nine overarching outcomes, yet, the interpreted size of content given some larger indicators made covering all of this content difficult.

It was also expressed that teachers felt there was too much content to cover the entirety of the 2017 Physics 30 course because the new document lacked 'fundamental content' that needed to be taught in addition to the expected indicators. For example, Chaz, an accredited physics teacher, said, "when I say that I think there's too much stuff in [the 2017 curriculum] it's because

I still teach the fundamental core stuff that was cut out [from the 1992 curriculum][11]." Specifically, Chaz mentioned the need to teach vectors and review content that was now included in Saskatchewan's Science 10 curriculum document, which he felt was not generally well taught. Chaz asked the science curriculum consultant about why kinematics (and vectors) had been removed from the new curriculum document, and,

> [the consultant] said, "We teach it in grade 10." I was like, "Really? So, you expect kids to remember what they learned in grade 10 all the way in grade 12." Grade 10 is a write off year—and this is coming from a front-line person.

To Chaz, the fundamental content that was removed from the 2017 Physics 30 curriculum document should still be included since we cannot expect our students to recall content they had learned in grade 10 science when they get to grade 12 physics.

This concern of too much content was not without dispute. Ian and Egon reported that they could cover all the content in this document. "The science consultant did unburden [the Physics 30] curriculum. I had never, in my entire time with the previous curriculum, finished it. Never. That was the same with the previous one as well because I've been through three" (Ian). To Ian, a long-time accredited teacher, the fact that he was able to 'finish' this curriculum document meant this document had less content to cover than the previous two documents. Egon, a non-accredited teacher, also expressed that he felt less pressed for time with this document and that he "moved at a brisk pace but was still able to finish it with time for review […]" and went on to explain that "in terms of actual curriculum, [he] wouldn't say it was too much—it was

[11] Chaz is referring to content that was in the 1992 curriculum document but has been "cut out" from (or not explicitly included in) the 2017 Physics 30 curriculum document such as uniform and uniform accelerated motion, graphing motion, and the specific instruction on vectors and mathematics with vectors.

sufficient." The amount of content in the 2017 curriculum document overwhelmed some teachers. Still, other teachers refuted this concern since they saw the 2017 Saskatchewan Physics 30 curriculum as being 'coverable' in one semester.

4.2.3. Stage 4 (Consequence) Concerns

Stage 4 concerns described teachers' worries, anxieties, and questions about the consequences the 2017 Physics 30 curriculum document could have for teachers, students, and physics instruction across Saskatchewan. Some of these concerns related to interactions between the 2017 curriculum and specific populations, such as the preparation of new (or non-science) teachers and preparation of students before taking Physics 30. Teachers were also concerned about how the increased emphasis on (what they called) "theoretical content" and the decreased emphasis on 'concrete' topics would impact their students. Finally, many teachers voiced concerns regarding course variation across the province due to the structure of the 2017 curriculum document.

4.2.3.1. Course Variation Across the Province. With the lack of suggested resources, and a lack of specific directions for instruction, "the probability of picking two teachers teaching the course the exact same way was low," (Gru). According to Alan, Chaz, Franz, Gru, Harley, Kye, Leilani, Nadia, and Olivia, the interpretation required of the 2017 curriculum document, with its outcome and indicator structure, may have resulted in many different Physics 30 courses across the province. For some, this variation was of concern because a Physics 30 course might not represent what they believed to be important to learn in physics. For others, this variation was of concern because the student experience relied greatly on the quality of their teacher. The 2017 curriculum document required teachers to interpret the content more than the 1992 Physics

30 curriculum document and, consequently, teachers were concerned this interpretation might have led to variance in students' experience of Physics 30 across the province.

Alan, Chaz, Harley, Kye, and Olivia expressed concerns about whether others would teach the course in a way they felt the subject should be taught. For example, Alan was concerned that some teachers may not challenge[12] their students enough;

> A lot of outcomes could just be turned into research for the students [...] that removes most of the stress of trying to get all of the intricate math up to grade level [...] I think that does students a disservice in the end. Because when I interpret it, I see an out for really challenging them [with the mathematics behind these outcomes]. (Alan)

To Alan, the variation in courses, caused by teacher interpretation, might result in less-prepared Physics 30 graduates who were not fully challenged (as he defines this term) by their teachers. Harley was also concerned about how teachers would enact the curriculum in their classes;

> I worry that—because indicators aren't mandatory—that lots of teachers are teaching [the 2017 curriculum document] in a teacher-directed way and not inquiry-based. I think it's very possible to teach it that way; you can focus on the indicators that are just the math.

Harley expressed that physics should be taught in an inquiry-based way and this was emphasized in her interpretation of the 2017 curriculum document. Nevertheless, as (accredited) teachers have the luxury of selecting which indicators they will teach to meet each outcome, a teacher may not teach those indicators (focused on inquiry) that were of import to Harley. Both Harley

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[12] To Alan, challenging his students meant to ensure students had a mathematical understanding and were able to take on rigorous problems. His example in this instance was of ensuring mathematical competence in modern physics when these outcomes did not specifically mention any mathematical analysis.

and Alan were concerned about the consequence of course variation across the province due to interpretation, or misinterpretation as they claimed, of what should be taught in Physics 30.

Franz, Harley, Nadia, Leilani, and Olivia were concerned that the student experience of Physics 30 with the 2017 curriculum document would depend more heavily on their teacher than with the 1992 document.

> The old curriculum put everybody on a level field and I think it allowed for weak teachers to compete with good teachers. The new curriculum really depends on the teacher because the way you interpret the curriculum could be so different with this document. (Franz)

With less formal direction on what to teach (such as the explanation given for each topic in the 1992 curriculum document) and more maneuverability in specific topics, the 2017 Saskatchewan Physics 30 curriculum document relied heavily on the physics expertise of the teacher. This was a worrying consequence for some teachers. “I think you need to tell teachers what to teach so everyone would know and every kid coming out would be doing the same things,” (Nadia). If the curriculum document allows for interpretation, there would be assumptions made (by physics-trained teachers) about what should be taught (mentioned by Nadia and Olivia); specifically, those who ‘knew physics’ made assumptions unbeknownst to those who were less experienced with the subject. Teachers were concerned that course variation, due to interpretation and hidden assumptions, meant that students could have very different experiences of physics across the province of Saskatchewan.

4.2.3.2. Preparation of New/Non-Science Teachers. Chaz, Franz, Gru, Harley, Marcos, Nadia, and Olivia were concerned about how new teachers, or those without physics/science as a trained subject area, would succeed in teaching the content in the 2017 curriculum document. For example, Gru asked whether the document was useful to those who he perceived as needing a curriculum document; “people who need the curriculum [document] the most are usually those that are least qualified to teach that subject; I would say that [the 2017 document] might not be as useful for them as the [1992] document.” Why might this document be less useful? Franz explained how the 1992 document was more useful to him;

> The [1992] curriculum was really nice in that you had the concepts clearly enumerated. It was really easy to know what to teach because it was, like, this equation, this equation, this equation, and focus on this concept, and this concept, and this concept and they even gave you examples; [the writers of the 1992 curriculum document] led you. So, as a beginning teacher, it was such a nice curriculum because you could just really stick to it.

As Franz pointed out, the 1992 Physics 30 curriculum document laid out each topic/concept in specific terms with examples and equations to be taught. For each topic, the 1992 curriculum included a brief explanation of the concepts and key ideas to be covered, numbered learning outcomes the teacher was expected to cover, and (for most content) teaching suggestions, activities, and demonstrations that may be used. For an example of this layout, see Appendix A which is a section from the 1992 Saskatchewan Physics 30 curriculum document for the concept of Newton’s Laws of Motion (and forces). The same concept in the 2017 curriculum document was represented as five indicators (of eleven) under one outcome (see PH30-FM2 in Saskatchewan Ministry of Education, 2017). One can understand how Franz, Gru, and others might consider the 2017 curriculum document to be more difficult for the new (or non-science trained) teacher since the document did not provide the teacher with a lesson on the content or teaching strategies; necessary things, as Gru said, for those who are less versed in physics.

In addition to concerns that the 2017 document did not provide a teacher with as much direction about the concepts and topics to be covered, some teachers voiced concerns about the assumptions made by those who wrote the curriculum document. To illustrate this, Nadia spoke of her experience in working with teachers writing the Chemistry 30 provincial exam:

> One of the other teachers, who had been teaching for over 20 years, […] was wanting to include questions that weren't specifically in the document. He said, "But everybody knows that when you teach this, you use this idea." We said, "The whole point is that people who are giving a [provincial exam] either haven't been teaching that long or are not chemistry people." So, to say *everybody* knows I think is an unfair statement.

Nadia used this example to showcase those assumptions made by people who know the subject area of instruction. To her, those teachers experienced in physics were more likely to also make those assumptions (because everybody experienced in a subject should know—as the experienced Chemistry teacher claimed) but the 2017 curriculum document does not explicitly spell out these assumptions. Assuming that people 'should know' is problematic for those who are either new to the subject or not trained in it as they likely do not know what they do not know. According to these teachers, the 2017 Physics 30 curriculum document appeared to be designed for those well-versed in the subject of physics and this was a concern for some. "As long as you have the necessary background [in physics], I don't think it's any more difficult to implement [this document]", said Jens, but the question then remained, what about those who lacked this background?

4.2.3.3. The Content is too Theoretical (or Not Rigorous Enough). Brad, Egon, Jens, Marcos, Nadia, and Pharris were concerned about the engagement of students and students' abilities to understand physics with the content added to Physics 30 in the 2017 curriculum document. Specifically, these teachers reported concerns about the shift from what they called "concrete" topics to "theoretical" or "abstract" ideas. Additionally, some teachers were concerned about the content focusing on what they (Alan and Pharris) called "the basics" as opposed to what they considered rigorous problem solving. These teachers felt that the focus on theoretical content made some outcomes in Physics 30 too light or not demanding enough.

Egon, Jens, Marcos, and Pharris each reported the shift from analyzing circuits in the 1992 curriculum to learning about electric and magnetic fields as an example justifying their concerns about the 2017 document focusing on theoretical or abstract ideas. For example, Egon said,

> From what I've heard, overall people are happy with the first bit of the document [modern physics] but that fields unit, everyone I've talked with seems to miss the old electricity [unit] more. I would echo that statement as well. I think it's because the old electricity [unit] was more tangible—more, here is something you can do and actually see the light bulb go on. As opposed to things like magnetic fields where, yes, we can see filings moving but we can't measure it as easily.

This new content was, to some teachers, less tangible than what was included with the 1992 document and this increase in abstraction, or ideas that were perceived to be less easily measured, was of concern to teachers. "When it's more abstract I find it a little bit harder for students to grasp the ideas," (Jens). The increase in abstraction with the content in the 2017 document was a concern for teachers as they felt students had difficulty accessing theoretical content compared to the "proven, concrete material" (as Egon called it) in the 1992 physics curriculum.

Some teachers reported concerns about the consequence of having more abstract topics in the 2017 curriculum than in the 1992 Physics 30 curriculum document. Egon, Marcos, and Pharris felt that physics content that was less esoteric and abstract was better for high school physics courses. According to Pharris, “if you can see things and measure them then it’s just easier to make sense of the physics.” When physics was measurable, according to Marcos, then “labs are easily done and it’s easier to teach with activities, which engages students and that’s what we want.” Direct manipulation and measurement were perceived as more engaging. Teachers also pointed to the outcomes on modern physics as focused on what they called ‘abstract’ concepts. “We want students to be engaged and it’s kind of hard to engage in modern physics. I think it’s just—by nature—more esoteric and abstract,” (Marcos). Teachers were concerned that the shift from what was described as concrete material in the 1992 curriculum document to more abstract physics concepts in the 2017 curriculum document might be difficult to learn and less engaging for students.

Egon also highlighted the need for less abstract topics for those students with no intentions of pursuing a future in theoretical physics (which he claimed was most of his students). “We have a lot of trades students who take physics because it's the one that you need for electrical work, power engineering, pipe fitters because that's where it's required. They're looking more for the [practical] electricity stuff,” (Egon). The electricity education these ‘trades students’ needed included what Egon called “concrete, proven material” such as Ohm’s Laws, circuit analysis, and determining power in a circuit—all topics in the old curriculum—as opposed to learning about electric fields and interactions within them, as could be found in the new curriculum document. Some teachers were concerned that shifting the content in Physics 30 from what they considered to be concrete, measurable topics to abstract ideas was negatively impacting students' engagement in and understanding of physics.

Finally, when asked what he did not like about the 2017 curriculum document Pharris replied, "the later outcomes seem too light." To Pharris, these later outcomes (in the fields and modern physics units) were too light because they "had more to do with understanding the basics as opposed to intense problem solving. You don't need equations or to solve many problems as opposed to learning about the topic and the people involved." Pharris reported that not having the "intense problem solving" and mathematical rigour made some topics in the 2017 Saskatchewan Physics 30 curriculum document appear too sparse in content. The abstract approach of some outcomes within the 2017 curriculum document, to Pharris, meant that students might only encounter the basic ideas of physics as opposed to digging deeper with problems.

4.2.3.4. Students are Unprepared for the Content of Physics 30. This concern theme was not specific to the Physics 30 curriculum document, but Alan, Chaz, Egon, Gru, Harley, Kye, Nadia, and Olivia all communicated concerns about the preparation of students entering Physics 30 courses given the changes to the Saskatchewan science curricula. Teachers claimed students' lack of preparation was a consequence of the restructuring of the grades 10 – 12 Saskatchewan science courses, specifically that these courses did not effectively prepare students in physics. The grade 10 science curriculum contained one physics-oriented unit aimed at teaching students about motion and the analysis of motion. Should students decide to pursue either physics or chemistry further after grade 10 science, they would need to enroll in Physical Science 20; this one-semester course focused on energy in both chemistry and physics with physics instruction on topics such as heat and waves. After completing Physical Science 20, students could take Physics 30, which focused on topics such as modern physics, kinematics and dynamics, conservation laws, and fields. There was no mathematics pre-requisite for Physics 30. To those teachers with concerns about students' preparedness for this course, this sequence of physics (and mathematics) instruction was insufficient resulting in consequences such as lost time (to review) and ill-prepared students.

Teachers were concerned about the assumption that students were expected to have learned the basics of motion in science 10. "There's 12 months, sometimes 18, from talking about kinematics [in grade 10] to Physics 30, so now we're talking about dynamics and they don't remember it. So, I struggle with how much kinematics was taken out of grade 12," (Denise). Some teachers found it difficult to teach those concepts in Physics 30 that were meant to be remembered from grade 10 science because it had been so long since students had explored those ideas—if they were even taught those concepts at all;

> In grade 10 most of the physics doesn't get taught. Right? If those teachers run out of time, physics is not their background, so they don't teach it. And if they do teach it, it's like, "read the textbook, teach it to yourself," (Chaz).

To mitigate these concerns, teachers, like Denise and Chaz, spent time in their course reviewing those concepts that were not included in the 2017 curriculum document but that they believed Physics 30 students needed to know. For the most part, these (now reviewed) concepts were covered in the 1992 Physics 30 curriculum document (e.g., uniform motion, uniform accelerated motion, etc.), but were now assumed to be pre-requisite knowledge. Teachers articulated that there was too large a gap between grades 10 and 12; "the flow from grade 10 to grade 12 in physics isn't cohesive so students just aren't prepared to go into Physics 30 from grade 10 science," (Alan). According to teachers, this gap in instruction resulted in students being ill-prepared to take on Physics 30 content.

Saskatchewan students, at least those students who entered Physics 30 at the time of writing this dissertation, received physics instruction in grade 11, but another concern for these teachers was that the Physical Science 20 course (implemented in all Saskatchewan schools in 2016) did not prepare students for Physics 30. “If Physical Science 20 was designed to prepare students for Physics 30 then I would be surprised. I wish it wasn’t a pre-requisite because I don’t see that there is actually pre-requisite knowledge in it,” (Gru). Students struggled to make connections between these courses (Olivia) and were not as prepared as they could have been for Physics 30. This disconnect in the material was also compounded, according to Marcos[13], by the fact that it was often not a “physics person” (his words) teaching Physical Sciences 20;

> Schools have teachers who aren’t physics teachers teaching Physical Science [20] and I know because I’m going to their classes and I’m reading presentations that are wrong. So, with [Physical Sciences 20], we can’t delve into the two sciences unless you have people who know both subjects [teaching] it.

Having one science course to prepare students for both Chemistry 30 and Physics 30 content was a concern for many physics teachers as their subject was often the one to lose instructional time.

It should be noted that not everyone communicated the worry that Physical Science 20 was not preparing students for Physics 30. For example, Leilani claimed that taking Physical Science 20 was not about preparing for the content in Physics 30 but about teaching students how to think in physics. To her, it was more important students have “good math skills and an open mind” (Leilani) to take on Physics 30. Despite Leilani’s view, teachers such as Chaz,

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[13] Marcos discussed the lack of physics-specialists teaching Physical Science 20 but was not concerned that this was hindering students’ preparation for Physics 30.

Harley, and Kye indicated there was a lack of consistent preparation of students for Physics 30 with the current structure of Saskatchewan's science curricula.

Like Leilani, other teachers (e.g., Chaz, Gru, Harley, Kye, and Olivia) mentioned the importance of strong mathematics skills for success in Physics 30 and that these mathematics skills were more important for success in Physics 30 than for Physical Sciences 20. Even so, according to Harley and Olivia, students were weaker in mathematics than they used to be. As a result, Harley reported having to spend time in her Physics 30 course teaching mathematics skills that she felt the students should already possess. Gru was also frustrated with students' difficulties in applying algebraic manipulation. As there was no mathematics pre-requisite, assuming students' competence in algebra was problematic[14]. Both Olivia and Chaz also mentioned concerns about students' weak mathematics skills; still, both Olivia and Chaz were uncertain when specific topics were taught in the mathematics curriculum. For instance, Chaz was certain students did not encounter trigonometry until grade 11 when it was actually taught in both grade 10 mathematics courses (Math 10 Workplace and Math 10 Pre-Calculus). This raises a curious point about whether teachers are familiar with the progression of content in the mathematics, as well as the science, curricula throughout grades 9 – 12 and the impact this lack of familiarity may have on review time in courses. Nonetheless, whether students were ill-prepared mathematically or unprepared to take on the science content in Physics 30, teachers expressed concerns about the impact of the current structuring of science curricula on students' abilities to succeed in Physics 30.

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[14] In the 1992 Saskatchewan Physics 20/30 curriculum document, Science 10 as well as one of either Physics 20 (grade 11 physics) or Mathematics 20 (grade 11 mathematics) was required to take Physics 30. In Mathematics 20, students learned topics such as absolute value equations, operations with irrational numbers, factoring polynomials (focused on trinomials), solving quadratic functions, probability, and proofs.

4.2.4. Stage 5 (Collaboration) Concerns

Stage 5 concerns in this study, based on the definition of Hall and Hord (1987, 2015) as described in section *2.3.3. Analyzing Concerns using the Concerns Based Adoption Model*, were those worries, questions, and anxieties about how other teachers were interacting with or receiving, the 2017 Physics 30 curriculum document. Concerns coded as stage 5 in this study either described teachers' (a) desire to interact with other teachers during implementation or (b) concerns regarding their colleagues' reception of the 2017 Physics 30 curriculum document.

4.2.4.1. How are Others Teaching this Curriculum? Teachers who asked questions about how others were teaching this new curriculum document commonly expressed feelings of isolation as a physics teacher. Comments such as "I don't have enough colleagues [who teach physics] to validate my assessments so I have to figure it out myself," from Alan and "I'd like to get together to talk physics with other teachers but don't have anyone here," from Brad showcased the isolation physics teachers felt in both urban (Alan) and rural (Brad) contexts. Teachers wondering how others were implementing the 2017 curriculum document felt they "didn't have access to that type of community," (Franz) meaning they had no community of peers with whom they could easily connect. Typically, Saskatchewan schools have one physics teacher, with some of the larger, urban schools having 2 (and very rarely 3 or more).

> When you're a physics teacher, you're kind of on your own. You're the only physics teacher, so you don't get to have a conversation with other people about what they're doing and what they think is important and how they interpret the curriculum and all those kinds of things. (Nadia)

Teachers wanted to talk with other physics teachers, to know how they were interacting with the 2017 curriculum document. As Franz said, "what I really need is just chit-chat; just to sit down with somebody or go to their school, you know, take a couple of hours and just go through how they do things like activities." Unfortunately, Franz was the only physics teacher in his school division, and he was pretty sure they wouldn't allow him to go to another school division for the day. Teachers in this study were curious about how other teachers were interpreting the curriculum, teaching Physics 30, and assessing the content; they wanted to discuss these topics with other physics teachers but many lacked access to these other teachers.

In Saskatchewan, there are very few professional development opportunities offered specifically for physics teachers. The science teachers' conference, Sciematics, was cancelled in 2016 and has yet to be hosted since (although it had been planned for spring 2020 and was postponed until spring 2021). In interviews, teachers mentioned a few opportunities hosted by the Universities of Regina and Saskatchewan, but these were primarily focused on teaching specific content in the curriculum (such as modern physics), not on the discussions and connections these teachers reported wanting.

The one professional development opportunity that was consistent for (accredited) teachers across the province was the accreditation seminar for physics. As a condition of their accreditation, teachers must attend this seminar at least once every five years unless they are granted exemption; exemptions are granted for exemplary service to the community of that subject (e.g., writing the curriculum document, offering subject-specific professional development, etc.) or for those with several areas of accreditation (as they only need to attend one session). So, for teachers accredited to teach physics in Saskatchewan, the one consistent professional development that could unite some of them was the accreditation seminar which was only attended every 5 years.

Feeling isolated, one teacher discussed her experience at an accreditation seminar based on the 2017 curriculum document. Denise attended the two-day accreditation renewal seminar and was excited to meet with other physics teachers and discuss how they approached the 2017 curriculum document; the same concern expressed by other teachers who communicated feelings of isolation. Unfortunately, upon attending the seminar she was disappointed with the experience because her entire peer group consisted of teachers who had not yet taught the 2017 curriculum document. “I sent this entire modern physics unit to a few new teachers around the province and they can use it but I didn’t get anything in return. What are other people doing in their classrooms?” she asked. Unfortunately, Denise did not receive an answer to her question. Despite attending what should have been a great place for peer connection, Denise was left still wondering how other people were teaching this curriculum document.

A sentiment of isolation as a physics teacher was expressed, but it was also noted that a few teachers communicated that participating in this research helped with those feelings. “It felt good to me to be able to talk about what physics was about and think about what physics sort of means,” said Brad, “I think about these things, but I don’t often have anyone to talk to them about.” The fact that they participated in this research was helpful for teachers, perhaps not to alleviate their concerns but to discuss their subject area and to think about more than the content being taught in their subject. “Just having a conversation about the philosophy behind physics and how you see it made me think about the way I think about it,” (Nadia). Teachers who were curious about how others were teaching this document wanted to connect with other physics teachers but lacked the community, supporting organization, or structure. After participating in this research, some teachers expressed appreciation for being able to talk about physics, and the 2017 Physics 30 curriculum document, with another (former) physics teacher—me.

4.2.4.2. Resistance Among Other Teachers. Franz, Gru, Ian, Kye, Leilani, and Marcos were concerned their peers would be, or were, upset with the changes to the 2017 curriculum document. Some teachers' resistance to the 2017 curriculum could have stemmed from a desire to continue teaching physics the same was as before.

> There's a lot of baggage from the old curriculum that's come into the new one. Teachers are still heavily teaching kinematics and whatnot with an emphasis on the math. I think a lot of teachers are still just busting out problems and just problem solving because it's easy, right? (Franz)

Despite a change in the document, there was some concern that teachers would simply continue to teach much of the content the way it was covered with the 1992 document. Kye pointed out that the 2017 physics curriculum document, to him, was designed so that teachers could focus more on "do students understand" than "can they give me the right number of significant figures?" The 2017 document was less about what Kye called "bookkeeping." To support Kye's point, neither the 2017 Physics 30 document nor Physical Science 20 documents explicitly mentioned that students use (or know) significant figures, whereas this was written into the 1992 Physics 20/30 document; perhaps this was an expected assumption? Olivia overtly (and vehemently) expressed that significant figures were vital to the success of any science education; this opinion stemmed from a job she had held where she assessed the parts per million of pollution in certain environments. Olivia continued to stress the use of significant figures in her courses despite there being no explicit outcome on their use in the 2017 Physics 30 curriculum document. Was Olivia holding onto baggage, as Franz called it, from the 1992 Physics 30 curriculum document or teaching what she believed to be important to knowing in physics? Either way, concerns regarding their peers' resistance to the 2017 Physics 30 curriculum were often explained as stemming from a desire to teach physics the way it had been taught before the 2017 Physics 30 curriculum.

Ian explained that this resistance from their peers might be attributed to fear of teaching physics content that was less focused on single, correct responses.

> Teachers, especially physics teachers, I think are not super comfortable with a lack of certainty. Physics became a big player in the human stage because we peddled a certain level of certainty. "I know what's gonna happen next and I can tell you even why it's gonna happen that way." People thought, "Wow! We had nothing this good before. So, let's see if you can come with all of the answers because, really, I'd love some answers." So, people, and this is often true of people who teach mathematics as well, are not super comfortable with ambiguity (Ian).

To Ian, we, as physics teachers, like to think we have answers; we like to work with problems that can be solved and when we are forced to teach content that does not necessarily have answers, it can be uncomfortable. To Gru,

> The new science courses [including Physics 30] encourage the actual gathering of data and analysis and I think that's uncomfortable for teachers […] because there is no answer key, you don't necessarily know how to set it up, and it's something that a lot of people aren't necessarily trained in.

Gru wondered if others were concerned about teaching the content in the 2017 Physics 30 because it required giving up some control of the content, giving up the expectation that there was always a correct answer, and stepping into the weird, less-explored side of physics.

Two very experienced physics teachers were not surprised by resistance to the 2017 Physics 30 curriculum document. Marcos and Ian each had more than 20 years of experience teaching physics in Saskatchewan schools and were both heavily involved in curriculum development at some point in their career. Both expressed concerns about teachers resisting the new topics in the curriculum document, particularly the removal of more concrete subjects (like circuit analysis) and integration of those topics characterized as having more uncertainty (such as quantum mechanics). As Ian put it, the 2017 curriculum "takes away some of [teachers'] favourite stuff and it highlights stuff they're not comfortable with." Both Marcos and Ian were concerned that their peers would resist the content introduced in the 2017 Physics 30 curriculum document. Nonetheless, they both felt this resistance would lessen with time (as they had seen with the 1992 curriculum change). "There are old guard out there who have a certain mind frame […] so, you have to wait for the next generation to see change. The old guard is very hard to convert," (Marcos). While this resistance from their peers was discussed, neither Marcos nor Ian was too concerned as they believed the resistance would lessen as new teachers began to take over the Physics 30 courses in Saskatchewan.

4.2.5. Summary of Concerns

Table 10 shows a summary of the concerns found in this study and their indicated stages. The stages of concern, as defined by Hall and Hord (1987, 2015), range from stage 0, or unconcerned, to stage 6, refocusing concerns; teachers in this study expressed concerns ranging from stage 2, personal concerns, to stage 5, collaboration concerns. As of spring 2018, two years after the initial implementation of the 2017 Physics 30 curriculum document, teachers' concerns were most evident at stage 4: concerns about the consequences of the 2017 curriculum document. Concerns focused on whether the 2017 document was less useful for the new (or non-science) teacher than the 1992 Physics 30 curriculum document, whether students were prepared to encounter the (as Marcos put it) more "esoteric" content, and how varied courses would be

Table 10

Summary of Concern Themes as Aligned with the Stages of Concern

Stage of Concern	Themes within this Stage of Concern	Teachers Reporting this Concern
Stage 0 Unconcerned	Not reported	None
Stage 1 (Informational) Concerns	Not reported	None
Stage 2 (Personal) Concerns	Lack of confidence in understanding of new content	Brad, Denise, Egon, Harley, Jens, Kye, Leilani, Nadia, and Olivia
	Teacher effectiveness in ensuring success on the provincial exam	Brad, Nadia, and Olivia
Stage 3 (Management) Concerns	Lack of instructions and resources	Brad, Egon, Franz, Gru, Jens, Nadia, Olivia, and Pharris
	There is too much content to cover	Alan, Chaz, Franz, Harley, and Olivia
Stage 4 (Consequence) Concerns	Course variation across the province	Alan, Chaz, Franz, Gru, Harley, Kye, Leilani, Nadia, and Olivia
	Preparation of new/non-science teachers	Chaz, Franz, Gru, Harley, Marcos, Nadia, and Olivia
	The content is too theoretical (or not rigorous enough)	Brad, Egon, Jens, Marcos, Nadia, and Pharris
	Students are unprepared for the content of Physics 30	Alan, Chaz, Denise, Gru, Harley, Kye, Nadia, and Olivia
Stage 5 (Collaboration) Concerns	How are others teaching this curriculum?	Alan, Brad, Denise, Franz, and Nadia
	Resistance among other teachers	Franz, Gru, Ian, Kye, Leilani, and Marcos
Stage 6 (Refocusing) Concerns	Not reported	None

across the province. Teachers in this study also had concerns about their management of the implementation of the 2017 Physics 30 curriculum document (stage 3) and the impact this document would have on their individual effectiveness as teachers (stage 2). Some teachers (Alan, Brad, Denise, Franz, Gru, Ian, Kye, Nadia, and Marcos) also reported concerns about collaboration (stage 5); these teachers were curious as to what other teachers were doing and were concerned about their peers' reception of the 2017 curriculum document. In answer to the question, "What were Saskatchewan Physics 30 teachers concerns about the 2017 Physics 30 curriculum document?"—at least for these 16 teachers—concerns varied but were most evident in regards to the consequences of the 2017 curriculum document, whether they could be as effective with the 2017 document, and what others were doing across the province.

4.3. Were there Connections between Teachers' Epistemic Beliefs about Physics and Their Concerns with 2017 Saskatchewan Physics 30 Curriculum?

As reported in the first section of this chapter, teachers largely concurred regarding both the certainty and coherence of physics knowledge and were largely concentrated toward one end of each of these continua. These visualizations can be seen in Table 11 (*Visualizing Teachers' Epistemic Beliefs About the Certainty of Physics Knowledge and their Concerns*) and Table 12 (*Visualizing Teachers' Epistemic Beliefs About the Coherence of Physics Knowledge and their Concerns*). Given the concentrations of teachers at one end of each of the continua of epistemic beliefs about (a) the certainty and (b) the coherence of physics knowledge, as depicted in Tables 11 and 12, it was difficult to discern any potential patterns connecting teachers' epistemic beliefs about the certainty or coherence of physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document.

Table 11

Visualizing Teachers' Epistemic Beliefs about the Certainty of Physics Knowledge and their Concerns

Concern	*Physics is absolute and unchanging*		*Physics is tentative and subject to change*
Stage 2			
Lack of confidence in understanding of new content		Denise Egon* Jens* Kye Leilani Nadia*	Brad* Harley Olivia*
Success on provincial exam		Nadia*	Brad* Olivia*
Stage 3			
Lack of instructions, resources, and time		Egon* Jens* Nadia* Pharris	Brad* Franz* Gru Olivia*
Too much content to cover			Alan Chaz Franz* Harley Olivia*
Stage 4			
Course variation		Kye Leilani Nadia*	Alan Chaz Franz* Gru Harley Olivia*

*indicates teacher is not accredited in physics

Table 11

Visualizing Teachers' Epistemic Beliefs about the Certainty of Physics Knowledge and their Concern

Physics is absolute and unchanging ◆————————————————◆ *Physics is tentative and subject to change*

Concern		
Stage 4 continued		
New/non-science teacher	Nadia*	Chaz Franz* Gru Harley Marcos Olivia*
Content is too theoretical (or not rigorous enough)	Egon* Jens* Nadia* Pharris	Brad* Marcos
Students unprepared for content	Denise Kye Nadia*	Alan Chaz Gru Harley Olivia*
Stage 5		
How are other teachers doing it?	Denise Leilani Nadia*	Alan Brad* Franz*
Resistance among other teachers	Ian Kye Leilani	Franz* Gru Marcos

*indicates teacher is not accredited in physics

Table 12

Visualizing Teachers' Epistemic Beliefs about the Structure of Physics Knowledge and their Concerns

Physics is a collection of isolated ideas	◆————————	————————◆	*Physics is a coherent system of connected ideas*
Concern			
Stage 2			
Lack of confidence in understanding of new content	Nadia*	Brad* Denise Harley Jens Kye	Egon* Leilani Olivia*
Success on provincial exam	Nadia*	Brad*	Olivia*
Stage 3			
Lack of instructions, resources, and time	Nadia*	Brad* Jens* Pharris	Gru Egon* Franz* Olivia*
Too much content to cover		Chaz Harley	Alan Franz* Olivia
Stage 4			
Course variation	Nadia*	Chaz Harley Kye	Alan Franz* Gru Leilani Olivia*

*indicates teacher was not accredited in physics

Table 12

Visualizing Teachers' Epistemic Beliefs about the Structure of Physics Knowledge and their Concerns

Physics is a collection of isolated ideas ◆———————————◆ *Physics is a coherent system of connected ideas*

Concern			
Stage 4 continued			
New/non-science teacher	Nadia*	Chaz Harley Marcos	Franz* Olivia* Gru
Content is too theoretical (or not rigorous enough)	Nadia*	Brad* Jens* Marcos Pharris	Egon*
Students unprepared for content	Nadia*	Chaz Denise Harley Kye	Alan Gru Olivia*
Stage 5			
How are other teachers doing it?	Nadia*	Brad* Denise	Alan Franz* Leilani
Resistance among other teachers		Kye Marcos	Ian Franz* Gru Leilani

*indicates teacher was not accredited in physics

As shown in Table 11, attempting to identify patterns when considering teachers' epistemic beliefs about the certainty of physics knowledge with their concerns was problematic as teachers were represented entirely at one end of the continuum. In Table 12, almost all of the teachers are represented near one end of the continuum (communicating the epistemic belief that physics knowledge was coherent) except Nadia, who communicated that physics knowledge was a collection of isolated ideas. This concentration also made it difficult to discern any potential patterns from Table 12 since Nadia was the only teacher sharing these beliefs; I could claim that Nadia had the concern but not necessarily that other teachers believing that physics knowledge was a collection of isolated ideas also reported any specific concerns. As teachers were all concentrated at one end of both the continua of epistemic beliefs about the certainty of physics knowledge and epistemic beliefs about the coherence of physics knowledge in this study, it was difficult to discern (or claim) any clear patterns connecting teachers' epistemic beliefs about these areas and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document.

Both the continua of epistemic beliefs about the source of physics knowledge and epistemic beliefs about the content of physics knowledge had multiple teachers represented on each side of neutral. As a result of this representation, I was able to discern some patterns indicating potential connections between teachers' epistemic beliefs about the certainty and content of physics knowledge and their concerns about the 2017 Saskatchewan Physics 30 curriculum document. I now discuss patterns interpreted from concerns expressed by those teachers and their differences or similarities in the placement along each of the continua of beliefs about both the source and the content of physics knowledge.

4.3.1. Teachers' Epistemic Beliefs About the Source of Physics Knowledge and Their Concerns

Before analyzing patterns indicating potential connections between teachers' concerns and their epistemic beliefs about the source of physics knowledge, it should be noted that, in this study, only three of the sixteen teachers indicated that they viewed physics knowledge as invented by humans with the other thirteen teachers believing that physics knowledge existed in an external reality, waiting to be discovered (see Figure 9). As depicted in Table 13, many concerns expressed by only one or two of those teachers who reported that physics knowledge was invented by humans were also expressed by teachers distributed across the other end of this continuum (those teachers believing the source of physics knowledge was reality); this similar distribution on both sides of the continuum made it difficult to identify patterns and connections between teachers' epistemic beliefs about the source of physics knowledge and their concerns about the 2017 curriculum document. As such, I looked for patterns where concerns (or the lack of concerns) communicated by all three teachers who saw physics as an invented discipline since—given the limited number of teachers communicating this belief—these patterns were discernable using visual representation.

4.3.1.1. Stage 2 (Personal) Concern, Lack of Confidence in Understanding the Content new to Physics 30. Teachers in this study reporting physics knowledge as being invented by humanity did not express any concern or lack of confidence in understanding the content added to the 2017 curriculum document. Only teachers' communicating that physics knowledge was discovered who also recognized that invention contributed to the source of physics knowledge expressed concerns about a lack of confidence in understanding the content added to the 2017 curriculum document. As shown in Table 13 and Figure 12, nine teachers who

Table 13

Visualizing Teachers' Epistemic Beliefs about the Source of Physics Knowledge and their Concerns

Concern	*Physics was discovered from an external reality* ◆			◆ *Physics was invented based on knowers' interactions with reality*
Stage 2				
Lack of confidence in understanding of new content		Denise Harley Jens* Leilani Olivia*	Brad* Egon* Kye Nadia*	
Success on provincial exam		Olivia*	Brad* Nadia*	
Stage 3				
Lack of instructions, resources, and time	Franz*	Jens* Olivia*	Brad* Egon* Nadia* Pharris	Gru
Too much content to cover	Franz*	Chaz Harley Olivia*		Alan
Stage 4				
Course variation	Franz*	Chaz Harley Leilani Olivia*	Kye Nadia*	Alan Gru

*indicates teacher was not accredited in physics

Table 13

Visualizing Teachers' Beliefs about the Source of Physics and their Concerns

Physics was discovered from an external reality ←→ *Physics was invented based on knowers' interactions with reality*

Concern						
Stage 4 (continued)						
New/non-science teacher	Franz*	Marcos	Chaz Harley Olivia*	Nadia*	Gru	
Content is too theoretical (or not rigorous enough)		Marcos	Jens*	Brad* Egon* Nadia* Pharris		
Students unprepared for content			Chaz Denise Harley Olivia*	Kye Nadia*	Alan Gru	
Stage 5						
How are other teachers doing it?	Franz*		Denise	Brad* Nadia*	Alan	
Resistance among other teachers	Franz*	Marcos	Leilani	Kye	Gru	Ian

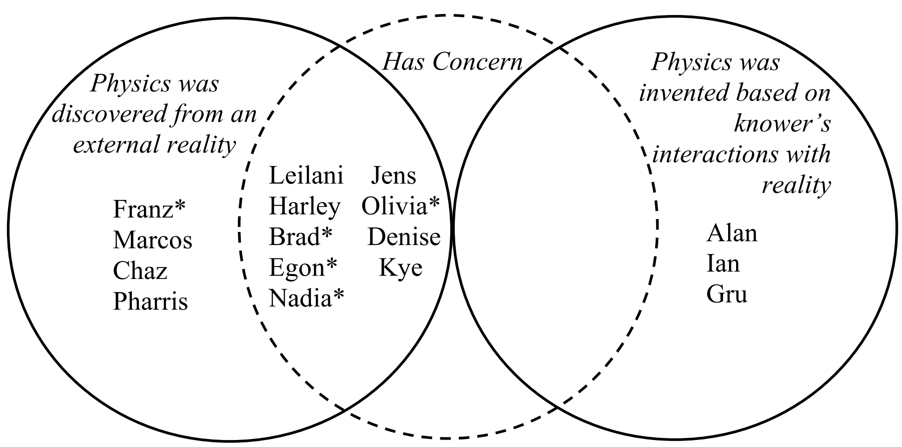
*indicates teacher was not accredited in physics

reported the belief that physics knowledge was discovered from an external reality reported this concern; none of the three teachers who reported physics knowledge as being invented expressed this concern. Of note, those nine teachers who expressed concerns about a lack of confidence in understanding content that was not in the 1992 curriculum document were all located nearer the centre of this continuum (see Table 13). Those teachers interpreted as being nearer the extreme of this continuum communicating the belief that physics knowledge was discovered from an external reality did not express concerns about a lack of confidence in understanding content added to Physics 30 with the 2017 curriculum document.

Gru, who described physics knowledge as being invented, discussed being comfortable with the contents of the curriculum document and attributed this comfort to his amount of formal physics education. "I'm a physics minor, so I have already taken courses on a lot of this stuff in university, whereas not a lot of non-physics people might have taken these topics," (Gru). Additionally, Gru emphasized the interpretation of data in his courses and that "this new

Figure 12

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Lack of Understanding the Content new to Physics 30



*indicates teacher is not accredited in physics

[Physics 30 course] is trying to encourage the actual gathering of data, the actual analysis […] and this can start to get into the messiness." To Gru, the messiness was interesting to teach because it required argumentation and interpretation—aspects of a subject invented by humans.

As a second example, Ian strongly agreed with Thomas Kuhn (as he reported in interviews) in that physics, and in fact, science as a whole was invented by humans. Ian read about the history and philosophy of science and it was because of his interest in these areas that Ian felt science should be taught with humanity (and its influence) in mind. To Ian, "we're not talking just about physics" when we teach physics courses, "we're talking about how physics acts and interacts within society." Ian asserted that the 2017 curriculum document told the story of science with particular attention to human interactions and influences, "in a way that [he] is happier with". At no point in our discussions did Ian identify any concerns about a lack of understanding of any of the content in the 2017 Physics 30 curriculum document that was not in the 1992 document.

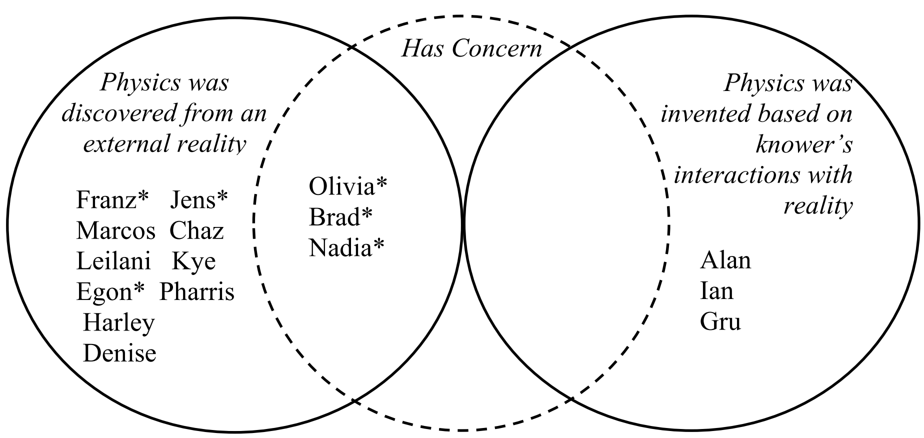
Considering the other half of this continuum, those teachers placed nearer the extreme representing the belief that physics knowledge existed in reality (Marcos and Franz) did not report concerns about a lack of confidence in understanding the content added to Physics 30 in the 2017 curriculum document. Yet, as depicted in Table 13, nine of the eleven teachers who communicated the belief that physics knowledge was discovered but also recognized that invention contributed to the creation of physics knowledge were the only teachers to communicate concerns about a lack of confidence in understanding any of the topics added to Physics 30 in the 2017 curriculum document. In fact, these nine teachers were the only ones to express concerns about a lack of confidence in understanding topics added to the 2017 curriculum document.

4.3.1.2. Stage 2 (Personal) Concern, Teacher Effectiveness in Ensuring Success on the Provincial Exam. As displayed in Table 13 and Figure 13, no teacher who believed that physics knowledge was invented by humans expressed concerns regarding their effectiveness in ensuring success on the provincial examination. Also depicted in Table 13, all of the teachers who were not accredited to teach physics and reported these concerns communicated the epistemic belief that physics knowledge was discovered from an external reality. Alan, Ian, and Gru (those teachers communicating the belief that physics knowledge was invented) were all accredited in physics; their students did not need to write this exam.

In interviews, Ian did not mention the provincial exam. When asked whether he would teach Physics 30 differently if his students had to write a provincial exam, Alan said "I don't think so. I think the [provincial exams] are too easy […] the way that I'm teaching makes sense." Alan reported that he would not be concerned about a provincial exam even if he had to prepare students to write this exam. Alan did not believe his course would change but Gru, on the other

Figure 13

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Effectiveness in Ensuring Students are Successful on the Provincial Exam



*indicates teacher is not accredited in physics

hand, indicated that he would likely approach teaching this curriculum differently if he were not accredited;

> I know—because I'm accredited—that if I don't emphasize something as much as the government would have emphasized it that I'm not gonna be punished and my kids aren't gonna be punished. Whereas, I also teach Biology 30 but I'm not accredited in Biology. In that [course] I take less risks because I need to make sure that my kids are prepared for that [provincial exam], which is 40 percent of their mark (Gru).

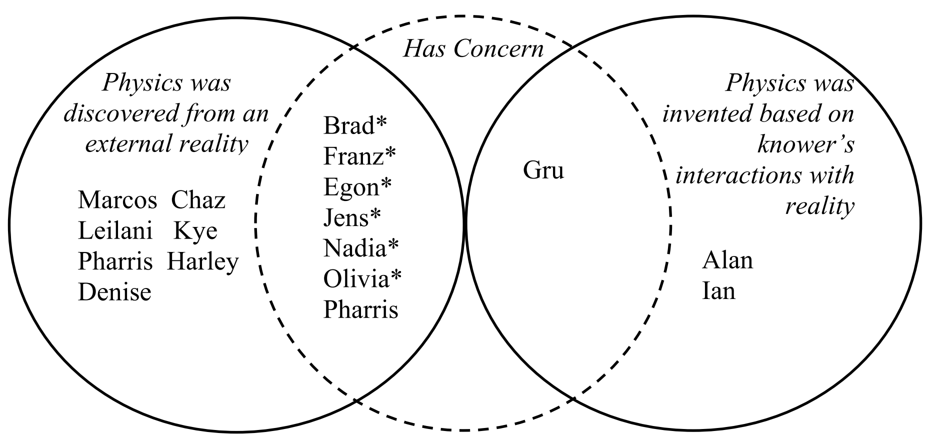
If he needed to prepare students for a provincial exam, Gru mentioned that he would take fewer risks with content to ensure students were not "punished" as a result. No teacher communicating the belief that physics knowledge was invented had to prepare their students for a provincial exam and none expressed concerns about this topic.

Concerns about their ability to prepare students for a provincial exam were reported by non-accredited teachers but not all non-accredited teachers communicated these concerns. As displayed in Table 13, all three teachers (Brad, Olivia, and Nadia) who were concerned about their ability to prepare their students for success on the provincial exam were located nearer the center of the continuum of epistemic beliefs about the source of physics knowledge. Two (Egon and Jens) of the three non-accredited teachers without this concern were also located in similar positions on this continuum. Franz was not accredited, did not express concern over the provincial exam, and was located very near the extreme end of the continuum indicating the belief that physics knowledge was discovered from an external reality. No teacher in this study communicating the belief that physics knowledge was invented by humanity had concerns about their effectiveness in preparing students for a provincial exam.

4.3.1.3. Stage 3 (Management) Concern, Lack of Instructions, Resources, and Time. In comparing teachers who reported this concern with their expressed beliefs about the source of physics knowledge, no clear pattern was evident in this study. As shown in Table 13 and Figure 14, this concern was expressed by teachers on both sides of the continuum of epistemic beliefs about the source of physics knowledge. Six of ten teachers represented nearer neutral but believing that physics knowledge was discovered expressed these concerns. Yet, one of two teachers represented near the extreme end of believing that physics knowledge was discovered also expressed these concerns as did one of three teachers who believed that physics knowledge was invented by humans. Given this similarity in representation of this concern being expressed by teachers in each of these groups[15], I interpreted this as suggesting that teachers' concerns

Figure 14

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about a Lack of Instructions, Resources, and Time



*indicates teacher is not accredited in physics

[15] The groups being considered on this continuum are those represented nearer the extreme of believing physics knowledge was discovered from an external reality (Marcos and Franz), those represented nearer neutral but believing that physics knowledge was discovered (Brad, Chaz, Denise, Egon, Harley, Jens, Kye, Leilani, Nadia, and Olivia), and those believing that physics knowledge was invented by humans (Alan, Gru, and Ian).

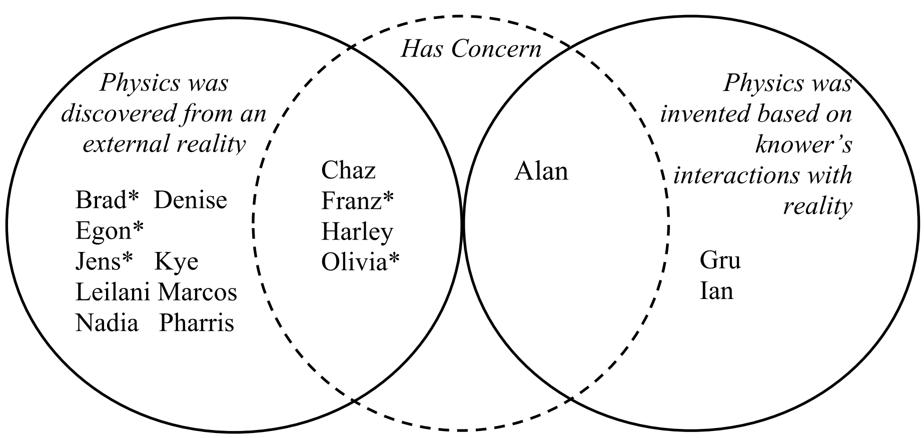
about a lack of instructions, resources, and time were not likely connected to their epistemic beliefs about the source of physics knowledge in this study.

4.3.1.4. Stage 3 (Management) Concern, There is too Much Content to Cover. No clear pattern was evident when comparing teachers who reported concerns about there being too much content to cover in the 2017 Saskatchewan Physics 30 curriculum document with their expressed beliefs about the source of physics knowledge. As shown in Table 13 and Figure 15, this concern was expressed by teachers on both sides of the continuum of epistemic beliefs about the source of physics knowledge. Given the representation of this concern being expressed by teachers in each of the groups[18] across this continuum, teachers' concerns about there being too much content to cover in the 2017 curriculum document did not appear to be connected to their epistemic beliefs about the source of physics knowledge in this study.

4.3.1.5. Stage 4 (Consequence) Concern, Course Variation in Physics 30 Across Saskatchewan. There was no apparent pattern when comparing teachers who reported concerns

Figure 15

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Too Much Content to Cover



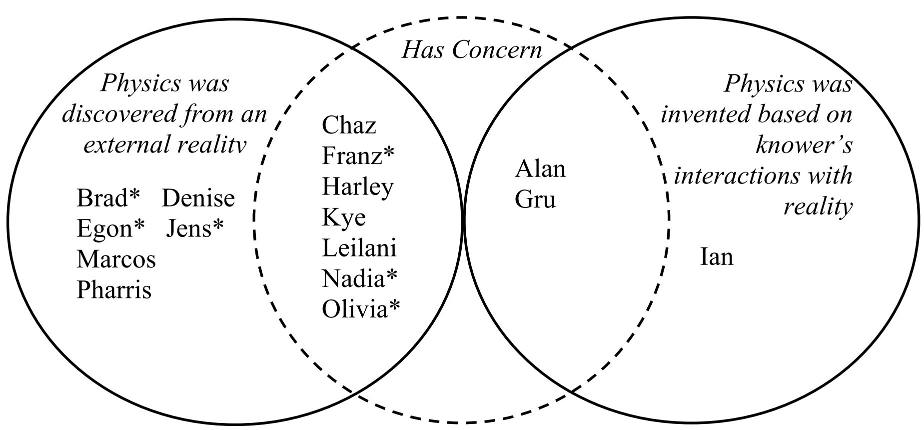
*indicates teacher is not accredited in physics

about course variation in Physics 30 courses across Saskatchewan with their expressed beliefs about the source of physics knowledge. As shown in Table 13 and Figure 16, this concern was expressed by teachers on both sides of the continuum of epistemic beliefs about the source of physics knowledge. Six of ten teachers represented nearer neutral but believing that physics knowledge was discovered expressed these concerns. Yet, one of two teachers represented near the extreme end of believing that physics knowledge was discovered also expressed these concerns as did two of three teachers who believed that physics knowledge was invented by humans. Given this similarity in representation of this concern being expressed by teachers in each of these groups, it would appear that these teachers' concerns about course variation in Physics 30 across the province of Saskatchewan were not connected to their epistemic beliefs about the source of physics knowledge.

4.3.1.6. Stage 4 (Consequence) Concern, Support for New and Non-Science Trained Teachers. As shown in Figure 17, teachers represented on both sides of the continuum of

Figure 16

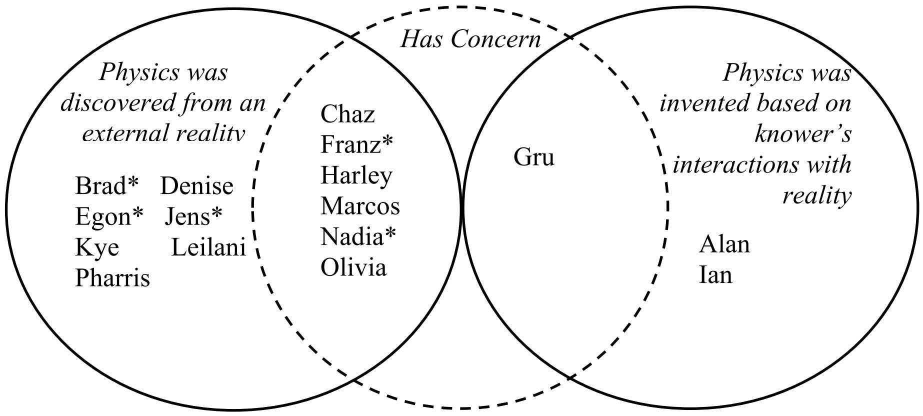
Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Course Variation in Physics 30 Across Saskatchewan



*indicates teacher is not accredited in physics

Figure 17

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Support for New and Non-Science Trained Teachers



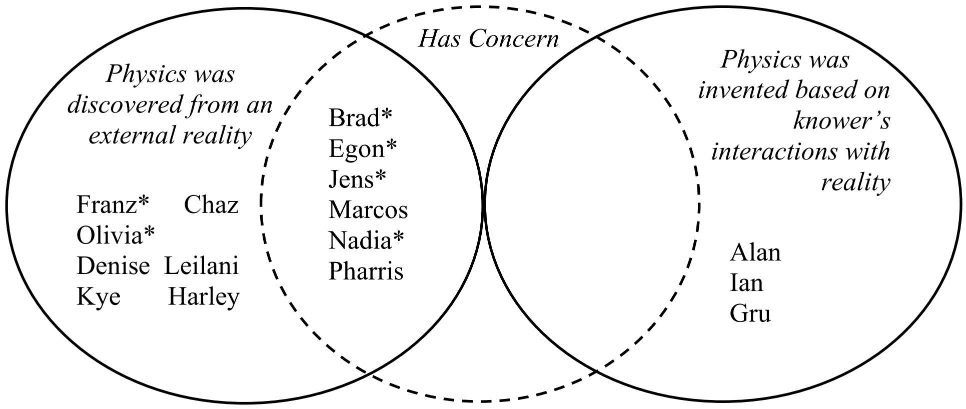
*indicates teacher is not accredited in physics

epistemic beliefs about the source of physics reported these concerns. As viewable on Table 13, these teachers were represented across the continuum of epistemic beliefs about the source of physics knowledge including one of three teachers who believed that physics knowledge was invented by humans. Teachers reporting concerns about support for new and non-science trained teachers were distributed across the continuum of epistemic beliefs about the source of physics knowledge; this suggested that these two constructs were not likely connected in this study.

4.3.1.7. Stage 4 (Consequence) Concern, The Content is Too Theoretical (or Not Rigorous Enough). A pattern was evident when considering teachers' epistemic beliefs about the source of physics knowledge and those teachers concerned about the content in the 2017 curriculum document being too theoretical (or not rigorous enough). Again, as shown in Table 13, and also presented in Figure 18, none of the three teachers who subscribed to the belief that physics knowledge was invented by humans reported this concern. Approximately half of those teachers believing that physics knowledge was discovered from an external reality reported this concern (ranging from the extreme to nearer the centre of this continuum) and the other half did

Figure 18

Venn Representation of Epistemic Beliefs about the Source of Physics Knowledge and the Content in the 2017 Physics 30 Document Being too Theoretical



*indicates teacher is not accredited in physics

not communicate any concern about the content being too theoretical or indicated that they preferred the theoretical content in the 2017 curriculum.

In support of the viewable pattern, Ian, the teacher placed at the furthest extreme indicating the belief that physics knowledge was invented by humans (see Table 13), discussed the increase in theoretical physics as a benefit of the 2017 curriculum document. Ian appreciated that the 2017 curriculum document "required a whole different change in understanding" since it forced Physics 30 teachers to apply 'newer' ways of thinking about the universe; "[Physics with Newton] was about forces and their interactions and now [physics was] actually more about fields and their interactions and that's a significant and profound difference in our thinking," (Ian). Ian did not express any concern about the content being too theoretical but did discuss why others might communicate this concern. "I am super comfortable with ambiguity," Ian said, but "teachers, especially physics teachers, are not comfortable with a lack of certainty." Ian claimed that the content added to the 2017 Physics 30 curriculum document, specifically field theory and modern physics, added a lack of certainty. According to Ian, those that wanted “a certain level of certainty,” were less likely to appreciate the 2017 curriculum document.

Comparably, six teachers who communicated the belief that physics knowledge was discovered from an external reality were concerned about the inclusion of more theoretical content and the removal of “concrete” (as described by Egon) topics. For example, Marcos, was represented nearer the end of the continuum indicating the belief that physics knowledge was discovered from an external reality, discussed that this shift to what he called “esoteric” content would be less engaging for students.

> Newton is so much more measurable and its [*sic*] labs are easily done. We want [students] to be engaged and it’s kind of hard to engage in modern physics. I think it’s just, by nature, more esoteric and abstract (Marcos).

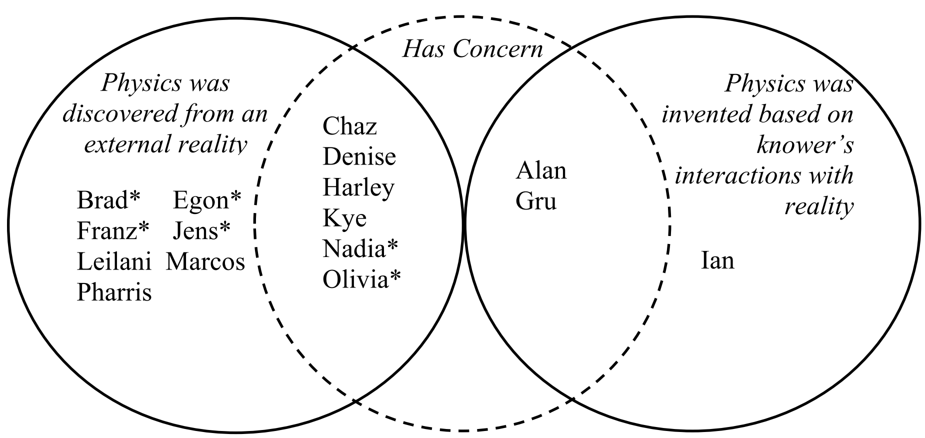
This sentiment was not limited to teachers represented nearer the end of the continuum indicating the belief that physics knowledge was discovered. Jens and Egon, represented nearer neutral on this continuum but still believing that physics knowledge was discovered, made similar claims. “I find [some ideas] to be a little bit more abstract and [these concepts are] harder for students to grasp” (Jens). Egon said he found this curriculum tougher for those students “needing the practical information.” To Egon, Marcos, and Jens, the concrete content, such as the electricity unit in the 1992 document (which focused on circuit analysis), was easier for students to learn when compared to the newly included, more abstract topics. These teachers reported similar concerns, yet their placement along the continuum of epistemic beliefs about the source physics ranged from neutral to extreme belief in physics knowledge as being discovered.

I interpreted the row in Table 13 representing teachers with the concern that the content was too theoretical in the 2017 curriculum document to indicate that those teachers believing that physics knowledge was discovered were more likely to express this concern. However, Kye provided a negative case from which to review this claim. Kye believed that physics knowledge was based in reality and did not worry about an increased abstraction in the curriculum document. When asked how he felt about teaching the modern physics and fields outcomes[16] from the 2017 Physics 30 course, Kye said "I feel pretty good about it," and went on to say that he liked "the theoretical stuff." Despite communicating similar epistemic beliefs about the source of physics knowledge, Kye reported that he was not concerned about the curriculum document being too theoretical (or not rigorous enough).

4.3.1.8. Stage 4 (Consequence) Concern, Students Were Unprepared for the Content in Physics 30. Figure 19 shows that teachers who were represented on both sides of the

Figure 19

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Students Were Unprepared for the Content in Physics 30



*indicates teacher is not accredited in physics

[16] The modern physics and fields outcomes included those concepts and topics which were not part of the 1992 Physics 30 course. These outcomes were also referred to as the theoretical or conceptual topics by teachers.

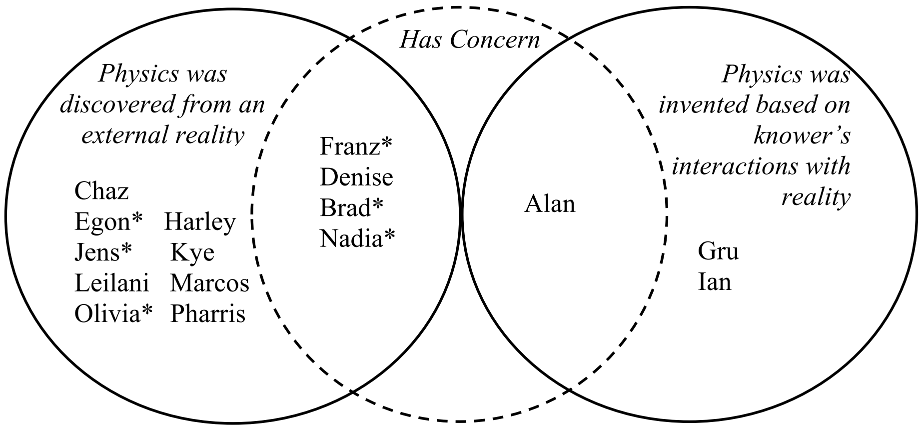
continuum of epistemic beliefs about the source of physics knowledge communicated concerns about students being unprepared for the content in Physics 30. Six of eight teachers reporting these concerns communicated the belief that physics knowledge was discovered. Table 13 gives a more nuanced view of the comparison of this concern and teachers' epistemic beliefs about the source of physics knowledge. Six of ten teachers who were represented near neutral but believing that physics knowledge was discovered reported concerns about students being unprepared for the content in Physics 30. Also, two of three teachers who communicated the belief that physics knowledge was invented by humans communicated this concern.

No teachers near either extreme on this continuum reported these concerns. However, it should be noted that Ian was the only teacher represented at the extreme end of the continuum representing the belief that physics knowledge was invented (and only two teachers were represented on the other end of this continuum). Given these factors, I did not perceive a pattern in this data (since teachers were represented in similar proportions on each side of this continuum) but recognize that this decision was influenced by the lack of teachers represented at the extreme ends of this continuum.

4.3.1.9. Stage 5 (Collaboration) Concern, How Were Other Teachers Teaching Physics 30? As viewable on Table 13 and Figure 20, teachers represented across the continuum of epistemic beliefs about the source of physics communicated these concerns. These teachers included one of three teachers who believed that physics knowledge was invented by humans. The even distribution of teachers who reported concerns (and wondered) about how other teachers were teaching the 2017 curriculum document across the continuum of epistemic beliefs about the source of physics knowledge suggested to me that these two constructs were not likely connected for teachers in this study.

Figure 20

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about How Other Teachers Were Teaching Physics 30?

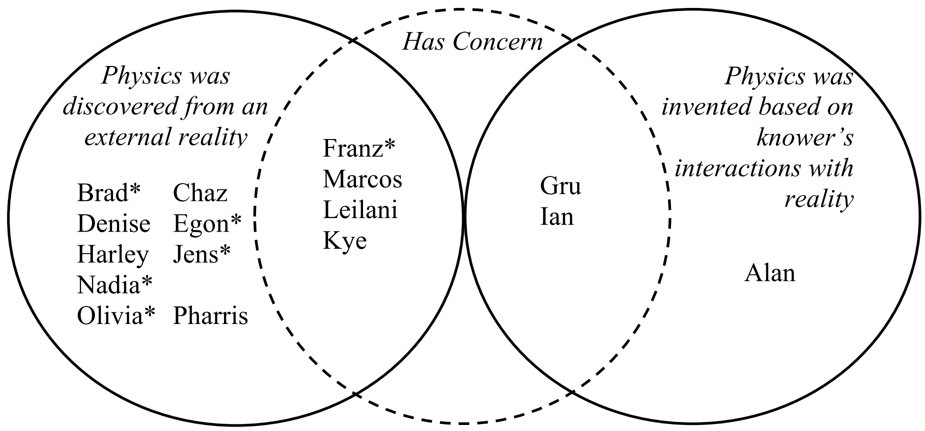


*indicates teacher is not accredited in physics

4.3.1.10. Stage 5 (Collaboration) Concern, Resistance Among Other Teachers. In comparing teachers who reported concerns about resistance among other teachers with their expressed beliefs about the source of physics knowledge, no clear pattern was evident in this study. As viewable on Table 13 and Figure 21, teachers represented across the continuum of epistemic beliefs about the source of physics communicated these concerns; this included two teachers represented near the extreme end of believing that physics knowledge was discovered, two teachers represented nearer neutral but believing that physics knowledge was discovered, and two teachers believing that physics knowledge was invented by humans. A pattern was not apparent between teachers' beliefs about the source of physics knowledge and whether they reported concerns about resistance among other teachers.

Figure 21

Venn Representation of Teachers' Epistemic Beliefs about the Source of Physics Knowledge and Concerns about Resistance Among Other Teachers



*indicates teacher is not accredited in physics

4.3.1.11. Summary of Connections Between Epistemic Beliefs about the Source of Physics Knowledge and Concerns. Only three teachers expressed the epistemic belief that physics knowledge was invented by humans, as opposed to physics knowledge being discovered from a reality external to the knower. This study suggests at least one plausible connection between these teachers' epistemic beliefs about the source of physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document.

First, and most clearly, none of the teachers believing that physics was invented reported concerns about a lack of confidence in understanding the content added to the 2017 curriculum document, whereas nine (of thirteen) teachers believing that physics knowledge was discovered—all from nearer the centre of this continuum—communicated this concern. My interpretation of the data suggests there might have been a connection between teachers' epistemic beliefs about the source of physics knowledge and concerns about a lack of confidence in understanding the content added to the 2017 curriculum document. In this study, teachers who communicated the epistemic belief that physics knowledge was invented but also recognized that physics knowledge might also be formed through invention were more likely than other participants to express concerns about a lack of confidence with content in the 2017 Physics 30 curriculum document that was not part of the 1992 document.

Second, none of the teachers believing physics was invented by humans were concerned about how to ensure their students would succeed on the provincial exam. Again, no teachers placed at the extreme end of the continuum communicating the belief that physics knowledge was discovered communicated this concern either. It should be noted that none of the teachers communicating the belief that physics knowledge was invented were required to prepare their students to write a provincial exam at the time of data collection; they were accredited. All non-accredited teachers expressed the belief that physics knowledge was discovered from an external reality, with Franz being placed at the extreme end of the continuum representing this belief and the others being placed closer to neutral. Three (Brad, Nadia, and Olivia) of six non-accredited teachers expressed concerns about preparing their students to write the final exam and their epistemic beliefs about the source of physics knowledge were also similar.

Third, no teacher communicating the belief that physics knowledge was invented by humans expressed concerns about the content in the 2017 Physics 30 curriculum document being too theoretical (or not rigorous enough). These concerns were reported by approximately half of those teachers (six teachers) communicating the belief that physics knowledge was discovered with five of these teachers being placed nearer to neutral on the continuum of epistemic beliefs about the source of physics knowledge. However, Kye was presented as a case which did not fit the pattern of teachers believing that physics knowledge was discovered as being more likely to be concerned about the content in the 2017 curriculum being too conceptual. Kye preferred teaching the theoretical, or conceptual, content in Physics 30.

4.3.2. The Content of Physics Knowledge and Concerns

As displayed in Table 14, there were potential connections between teachers' epistemic beliefs about the content of physics knowledge and several areas of concern regarding this document. Concerns with potential connections to teachers' epistemic beliefs about the content of physics knowledge included concerns regarding (a) a lack of confidence in understanding the content new to Physics 30 in the 2017 curriculum document, (b) whether they would be effective in preparing students for the provincial exam, (c) the lack of instruction/resources provided with this document, (d) the theoretical underpinnings of this document, and (e) students' unpreparedness for Physics 30.

4.3.2.1. Stage 2 (Personal) Concern, Lack of Confidence in Understanding of the Content new to Physics 30. As depicted in Figure 22 and Table 14, teachers in this study reporting the epistemic belief that the content of physics knowledge was conceptual and qualitative were more likely to report concerns regarding a lack of confidence in understanding the content new to Physics 30 in the 2017 curriculum document. This finding was surprising since—to me and voiced by participants—the 2017 curriculum document emphasized conceptual (qualitative) physics more than mathematical explanations, especially when compared with the 1992 Physics 30 curriculum document.

Nine teachers were concerned about their lack of experience with, or knowledge of, the content added to the 2017 Physics 30 curriculum document. Six of these nine teachers believed that the content of physics knowledge was conceptual and qualitative. These six teachers ranged from extreme placement (Harley) to near neutral placement (Nadia) on the side of the continuum

Table 14

Visualizing Teachers' Epistemic Beliefs about the Content of Physics Knowledge and their Concerns

Concern	*Physics is mathematics-based in formulae* ◆							◆ *Physics is concept-based and qualitatively explainable*
Stage 2								
Lack of confidence in understanding of new content			Leilani	Egon* Jens*	Nadia*	Denise	Brad* Kye Olivia*	Harley
Success on provincial exam					Nadia*		Brad* Olivia*	
Stage 3								
Lack of instructions, resources, and time	Franz*		Pharris Gru	Egon* Jens*	Nadia*		Brad* Olivia*	
Too much content to cover	Alan Franz*	Chaz					Olivia*	Harley
Stage 4								
Course variation	Alan Franz*	Chaz	Leilani Gru		Nadia*		Kye Olivia*	Harley

*indicates teacher was not accredited in physics

Table 14

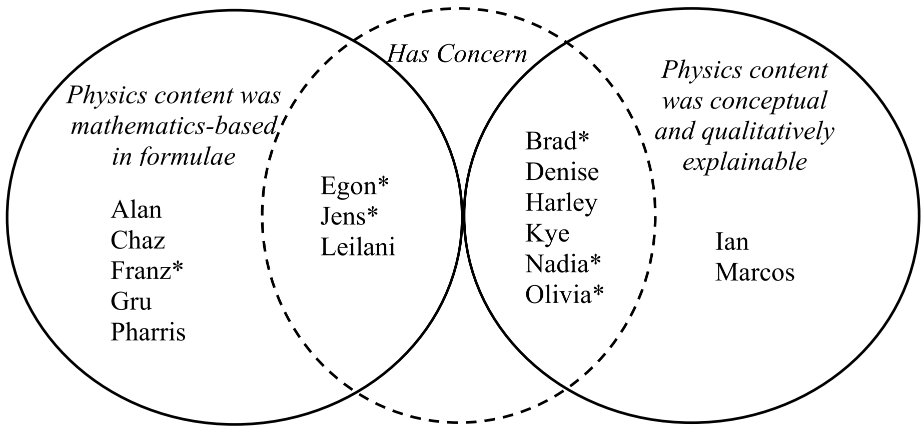
Visualizing Teachers' Beliefs about the Content of Physics Knowledge and their Concerns

Concern	*Physics is mathematics-based in formulae*							*Physics is concept-based and qualitatively explainable*
Stage 4 (continued)								
New/non-science teacher	Franz*	Chaz	Gru		Nadia*		Olivia*	Harley Marcos
Content is too theoretical (or not rigorous enough)			Pharris	Egon* Jens*	Nadia*		Brad*	Marcos
Students unprepared for content	Alan	Chaz	Gru		Nadia*	Denise	Kye Olivia*	Harley
Stage 5								
How are other teachers doing it?	Alan Franz*				Nadia*	Denise	Brad*	
Resistance among other teachers	Franz*		Gru Leilani			Ian	Kye	Marcos

*indicates teacher was not accredited in physics

Figure 22

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Lack of Confidence with Understanding of the Content new to Physics 30



*indicates teacher is not accredited in physics

of epistemic beliefs about the content of physics knowledge representing those who believed that physics knowledge was conceptual. The only two teachers communicating that physics content was qualitative that did not have this concern (Ian and Marcos) were both extremely experienced teachers (20+ years). However, Brad and Harley were also extremely experienced teachers who believed that physics knowledge was conceptual but they both communicated this concern. This indicates that concerns about a lack of confidence in understanding the content new to Physics 30 in the 2017 curriculum document were not specific to the less experienced teachers.

These individuals' concerns regarding their lack of confidence in understanding the content added to Physics 30 in the 2017 curriculum were frequently related to the outcomes about modern physics and fields. Teachers were concerned about ensuring they could be effective in explaining the concepts in these topics that had not been required by the 1992 Physics 30 curriculum document. For example, Kye was concerned with teaching the new content in the 2017 document because he "wasn't as experienced in it so it involved a bit more research to learn it and [… more] research to figure out a way to bring it down from my head to something that would be approachable for [students]." In this instance, Kye connected his concern to a lack of experience with certain topics as well as his desire to fully synthesize and understand the content before teaching it to his students. This sentiment of fully understanding the information before teaching a topic was also expressed by Nadia, Olivia, and Harley—all teachers reporting the belief that physics knowledge was conceptual and qualitatively explainable.

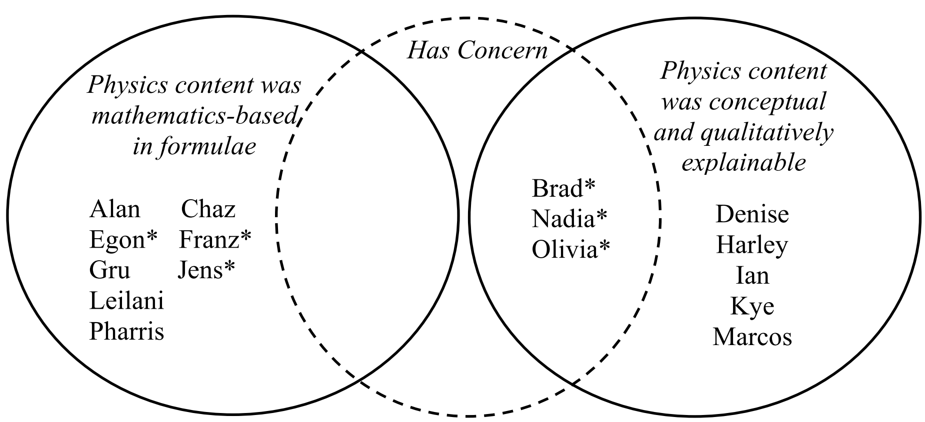
Concerns related to teachers' lack of confidence in understanding the content in Physics 30 were not unique to those teachers believing that physics knowledge was conceptual and qualitatively explainable. As shown in Table 14, three teachers who believed that physics knowledge was based in mathematics (but was also somewhat conceptual) also communicated this concern. Both Leilani and Jens discussed how they, similar to those teachers mentioned above, felt inexperienced with new topics in the 2017 curriculum document. Teachers expressed concerns regarding understanding the newly added content in the 2017 Saskatchewan Physics 30 curriculum document because of a lack of experience; in this study, these concerns were expressed by both teachers reporting the belief that physics knowledge was mathematically oriented and teachers reporting the belief that physics knowledge was conceptual and qualitative.

None of the three teachers (Alan, Chaz, and Franz) placed near the end of the continuum representing the belief that the content of physics knowledge was mathematical (see Figure 11) expressed any concern about a lack of confidence in their understanding of content in the 2017 curriculum. Teachers distributed between neutral and the extreme end of believing that physics knowledge was conceptual and qualitative on this continuum reported concerns about teaching content new to the 2017 curriculum document. Yet, the only mathematically oriented teachers that reported this concern also communicated that some part of physics knowledge was conceptual; these teachers were placed nearer neutral on this continuum (Egon, Jens, and Leilani). These results suggest that those teachers communicating the belief that the content of physics was, at least somewhat, conceptual and qualitative were more likely to express concerns about a lack of confidence of their understanding of content in Physics 30.

4.3.2.2. Stage 2 (Personal) Concern, Teacher Effectiveness in Ensuring Success on the Provincial Exam. As depicted in Table 14 and Figure 23, concerns about personal effectiveness in ensuring success on the provincial exam were exclusive, in this study, to those non-accredited teachers who believed that physics knowledge was qualitative and conceptual (Brad, Nadia, and Olivia). Other non-accredited teachers (Egon, Franz, and Jens) all communicated the belief that the content of physics knowledge was mathematically oriented and none of these three teachers reported concerns about their effectiveness in preparing students for

Figure 23

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns about Effectiveness in Ensuring Student Success on the Provincial Exam



*indicates teacher is not accredited in physics

the provincial exam. Both Brad and Olivia were represented nearer the extreme end of believing that physics content was qualitatively explainable with Nadia being somewhat more towards the centre of this continuum (shown in Table 14).

Non-accredited teachers who believed physics knowledge was qualitatively explainable were concerned about their effectiveness in preparing their students for the provincial exam. These teachers were often left asking questions such as "what will they ask on the provincial exam?" (Brad). Olivia felt she had "to teach [the 2017 curriculum] with the math because [she's] not accredited and [her] kids have to write the [provincial exam]." These teachers anticipated the provincial exams would focus on formula-use or mathematically oriented physics. These teachers explained that it was easier to predict the formula-based questions that were going to make up the bulk of the provincial exam with the 1992 curriculum document than it was with the less formula-driven topics in the 2017 curriculum document; "I'm kind of frustrated with [the 2017 curriculum document] right now because [it] doesn't actually have that many equations, but then when you go into the [provincial exam] there is a ton of equations," (Olivia). Egon, Jens, and Franz were also not accredited, yet, none of these three teachers expressed concern over their ability to prepare students for the provincial exam; these teachers, who communicated the belief that physics knowledge was mathematically oriented, tended to be concerned with teaching all of the outcomes as opposed to ensuring they 'properly' interpreted the outcomes as they will be assessed on the provincial exam.

Teachers believing that physics knowledge was qualitative and conceptual who discussed the provincial exams typically raised the issue of what was going to be assessed. Although she did not express concerns about preparing her own students for a provincial exam, accredited teacher Harley accurately encapsulated how these teachers were feeling;

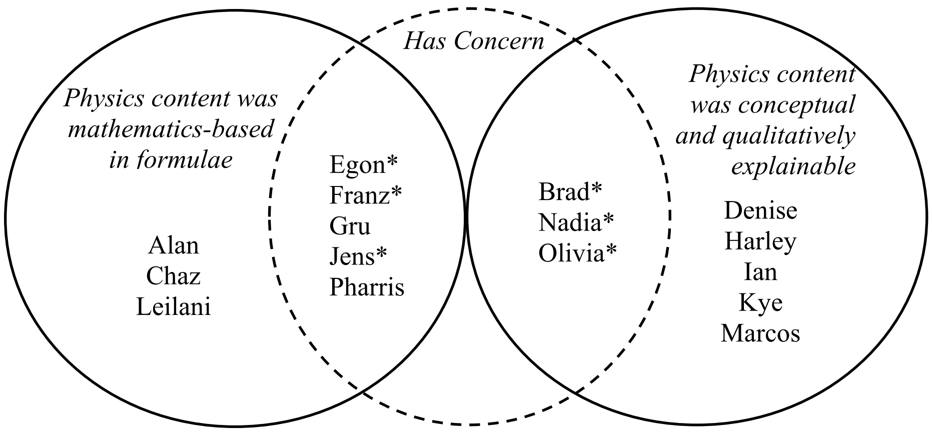
> Lots of the conceptual indicators aren't going to be on the [provincial exam] and everybody knows that. It's like [the curriculum document and the exam] are two polar opposites. You have the science consultant saying "We want it to be done this way and if it's not on the [provincial exam] then you should more rigorously evaluate it yourself;" whereas we've got the [provincial exam] over here and we can only test on concrete subjects, so then the teachers are like, "Well, if I want my students to succeed on the [provincial exam] I'm only teaching these things."

Teachers preparing their students for a provincial exam were teaching this curriculum document to what they predicted would be a quantitative, formula-based assessment. Brad even went so far as to say that he determined on which outcomes to focus by finding those indicators which had verbs that could be measured or assessed using multiple choice questions; many of these indicators were those focused on mathematical equations (as Olivia had mentioned). Teachers reported a disconnect between the provincial exam—focused on mathematical content—and the curriculum document—with many conceptual indicators. In this study, only non-accredited teachers believing that physics knowledge was conceptual and qualitative (Brad, Nadia, and Olivia) expressed concerns about preparing their students for the mathematics-heavy provincial exam.

4.3.2.3. Stage 3 (Management) Concern, Lack of Instructions and Resources. As shown in Table 14 and Figure 24, teachers represented on both sides of the continuum of epistemic beliefs about the content of physics had concerns about a lack of instructions and resources with the 2017 curriculum document. All non-accredited teachers expressed this concern and the only accredited teachers to communicate this concern believed that the content of physics knowledge was mathematics-based. The type of resources sought by teachers on

Figure 24

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and a Lack of Instruction and Resources with the 2017 Curriculum



*indicates teacher is not accredited in physics

either side of the continuum varied. Teachers believing that physics knowledge was conceptual and qualitatively explainable wanted resources describing the intended layout of the Physics 30 course based on the 2017 curriculum document (i.e., how much time should they spend on each topic) and guidance on which topics they should focus throughout Physics 30. Those teachers communicating the belief that physics knowledge was rooted in mathematics and formulae who reported concerns about a lack of resources sought direction on how much time to allocate during a course to each outcome and wanted resources aimed at teaching the conceptual aspects of the 2017 Physics 30 curriculum document.

Teachers who believed that the content of physics knowledge was qualitatively represented and were concerned with the lack of resources and instruction for the 2017 Physics 30 curriculum document expressed a need for resources to help with time management and guide how content should be taught. Both Olivia and Brad, who were placed nearer the extreme end of believing physics knowledge was qualitative, discussed the need for more resources to help determine what “they” (referring to those persons writing the provincial exam) were going to ask. Olivia and Brad wanted more direction to ensure they could prepare students for the provincial exam. Nadia, who believed physics knowledge was qualitative but recognized that mathematics may also contribute to the content of physics knowledge, wanted curated materials with which to teach the content; she wanted ready-to-use resources. Desiring direction on the specifics to be taught, Nadia was overwhelmed by having to prepare a completely new course. In this study, teachers who believed that the content of physics knowledge was conceptual and were concerned with a lack of instructions and resources with the 2017 curriculum document were concerned about the time it took to prepare to teach Physics 30 and wanted more direction on the specifics that should be taught (particularly if preparing their students to write a provincial exam).

Egon, Franz, Gru, Jens and Pharris all believed that the content of physics knowledge was mathematically oriented and reported concerns about a lack of instructions, resources, and time. These teachers raised questions about how much time to allocate to each topic and were concerned about the lack of resources that explained the newly added, more abstract topics (i.e., modern physics and fields). Both Gru and Jens mentioned that they wished the curriculum document provided expected time for each unit. When discussing the new content in the 2017 curriculum, specifically modern physics, Jens said, “obviously you can design an entire course on that stuff alone, so it's kind of hard to know how to allocate your time.” Gru expressed a similar concern, wanting to know what was expected for each set of general outcomes (or unit). To solve this problem, Gru reverse engineered a course design from a prototype provincial exam even though he was an accredited teacher. He was grateful to be treated as a professional able to interpret this new curriculum document, yet Gru also conveyed that “sometimes, having some criteria to make those decisions upon is useful," and this was missing from the 2017 curriculum document.

Another aspect noted among teachers in this study who believed that the content of physics knowledge was mathematically oriented and were concerned about a lack of resources was a need for more resources to explain the abstract, or more theoretical, concepts in this document. Franz, who was placed on the extreme end of believing that the content of physics knowledge was based in mathematics, found it extremely difficult to find resources since he taught in a language other than English[17].

> I'm trying to explain—an electron goes in a circle at the speed of light, you're going the speed of light, and the electron and... it's hard to explain because it's so abstract. [There are] a lot bigger (*sic*) variety of explanations—like you can go on YouTube and people are explaining things—you've got 50 000 explanations in English and you can just find one that really works and BOOM you bring it to the kids. Whereas, me, I mean I've got like 3 [in my language of instruction] and the 3 of them are all garbage. (Franz)

Franz did not discuss a lack of resources for the mathematical aspects of this course, his worry was in providing good resources for abstract explanations. Similarly, Egon wanted resources to support his instruction of those theoretical topics that he found difficult to teach in a "hands-on" manner. Specifically, Egon mentioned wanting resources to help him teach the 'electricity and fields' unit in the 2017 curriculum compared to the 'electric circuits' unit (which focused primarily on calculation) from the 1992 curriculum document.

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[17] The language has not been specified to maintain anonymity of the participant.

> There is less supporting material, I've found, especially for that electricity and fields unit, than I would like and I have yet to see it come to textbooks available. […I would like a textbook that] I can hand it to a student to say, "Here's something that can help support you in everything that I'm teaching. If you don't understand this, go read this page." Right now, I have to go, "Oh, you don't understand this, here's a Wikipedia article and a scientific journal," which most of them will look at and go "Is it too late to drop this class?" (Egon)

Egon was not concerned with his ability to teach this content, as discussed in section *4.2.3*, but he was concerned about his ability to provide resources with alternative explanations for students on those abstract topics such as the content in the 'fields' unit. In lieu of a textbook to which he could refer students, Egon was collating resources the best he could to provide students alternative explanations for concepts. Unfortunately, students wanted to "drop" the class (or quit studying physics) as a result of having to sift through too many resources. Teachers who believed that the content of physics knowledge was mathematically oriented who voiced concerns regarding a lack of instructions or resources with the 2017 curriculum document wanted resources that told them how much time to spend on content (two teachers nearer the center of the continuum) and resources to help explain the more abstract content (teachers reporting beliefs across the half of the continuum indicating the belief that the content of physics knowledge was mathematics-based).

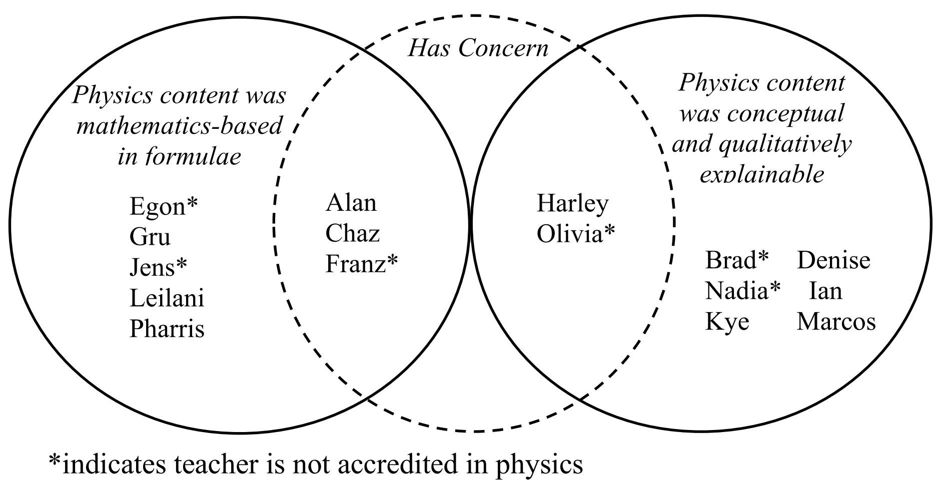
Finally, as presented in Figure 25, more teachers in this study who believed that the content of physics knowledge was mathematically oriented reported concerns regarding a lack of instruction about and resources available for this document than those teachers believing that physics knowledge was conceptual. However, also depicted in Table 14, teachers expressing concerns about a lack of instructions, resources, and time were distributed across the continuum of teachers' epistemic beliefs about the content of physics. Concerns about a lack of instructions and resources were not specific to teachers at any location across the continuum of epistemic beliefs about the content of physics knowledge.

4.3.2.4. Stage 3 (Management) Concern, There is Too Much Content to Cover. Five teachers expressed concerns about having too much content to teach. When viewed in a Venn-diagram, as shown in Figure 25, I did not discern any evident pattern. When viewing these beliefs along the continuum of epistemic beliefs about the content of physics knowledge and considering concerns regarding too much content in the 2017 curriculum document, as depicted in Table 14, irrespective of with which end of this continuum teachers aligned, this concern was only expressed by teachers at extreme ends of this continuum.

As presented in Table 14, two of these teachers were represented near the extreme end of the continuum representing those believing that the content of physics knowledge was

Figure 25

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About too Much Content in the 2017 Curriculum Document



conceptual. Three of these five teachers were represented near the extreme end of the continuum representing those believing that the content of physics knowledge was almost entirely mathematics-based. For those believing that physics knowledge was rooted in mathematics, this concern was connected to a (teacher-imposed) mathematics focus which made it difficult to teach all of the content within this document in one semester. On the other extreme of the continuum, those teachers believing that physics knowledge was qualitative and conceptual were concerned that having to review simple mathematics concepts took away from their time to teach physics and made it difficult to teach all of the content in the 2017 Saskatchewan Physics 30 curriculum document.

Harley and Olivia, the two teachers with this concern who believed that the content of physics knowledge was qualitative and conceptual, were frustrated with having to spend time in their physics courses focusing on what they considered to be mathematics instruction. Harley had trouble teaching the entire curriculum document because, as she put it, she “had the luxury” of being accredited and could choose where to put her focus and energy. Harley was particularly passionate about having students fully understand the new modern physics content as these ideas were fundamental to physics in her opinion; “I do think there are fundamental ideas in physics. Relativity for sure. Quantum mechanics and the standard model are big ones too,” (Harley). Harley was frustrated with the “weak mathematics skills” with which students entered her Physics 30 class; she attributed this lack of skill to the change in the mathematics curriculum in Saskatchewan which was fully implemented in 2012. “I think the changes in the math curriculum has affected physics [students],” (Harley). Due to this perceived weakness in mathematics, Harley dedicated course time teaching math when she should be teaching physics.

Similarly, Olivia was concerned about her students' weak mathematics skills, specifically "when [her class] get[s] into an equation and it's been manipulated, [the students] get lost really quickly." Having to review these 'simpler' mathematics skills made it difficult for Olivia to teach the entire curriculum.

> There's lots of indicators in each outcome and, ok, so one of the indicators deals with velocity and vectors and that's huge on its own. It can be massive so there's the one indicator in there that lists all the different equations and that alone is huge—to go through and show how to use and when to use those equations and in what circumstances you use those equations—that is massive on its own. (Olivia)

Olivia felt the need to teach her students "how to use and when to use" equations while also taking time to coach students through skills such as equation manipulation. Having to teach this material that was not explicitly included in the 2017 Physics 30 curriculum document was a concern for her since it prevented her from having the time to teaching the entire Physics 30 curriculum.

Olivia, unlike Harley, had to prepare her students for a provincial exam. As discussed in *4.2.2.2. There is Too Much Content to Cover,* Olivia struggled to reconcile her beliefs that physics content was conceptual with what she perceived to be a mathematics-heavy provincial exam. When asked if she would teach less mathematics in Physics 30 if she were accredited, Olivia responded, "Yeah. I'd rather the kids understand the concepts of rotational motion than necessarily have that calculation." Olivia, much like Harley, would have rather spent her class time teaching the concepts in physics as opposed to mathematics.

On the other end of the continuum of epistemic beliefs about the content of physics knowledge, Chaz, Franz, and Alan were all placed near the end representing the belief that the content of physics knowledge was based in mathematics and expressed concerns regarding too much content in the 2017 curriculum document to teach. Franz communicated that he was concerned that there was too much content in the 2017 curriculum document but he recognized that this may have been his perception; if Franz were accredited, "[he] would probably take out a few things." For Franz, the 2017 curriculum document was "too packed" but he did not discuss why he had this concern other than indicating that he may not have felt this way if he were accredited. As discussed in *4.2.2.2. There is Too Much Content to Cover*, Chaz's concerns were focused on the removal of what he called "fundamental content" which included graphing kinematics, mathematics skills, and explicit instruction on vectors.

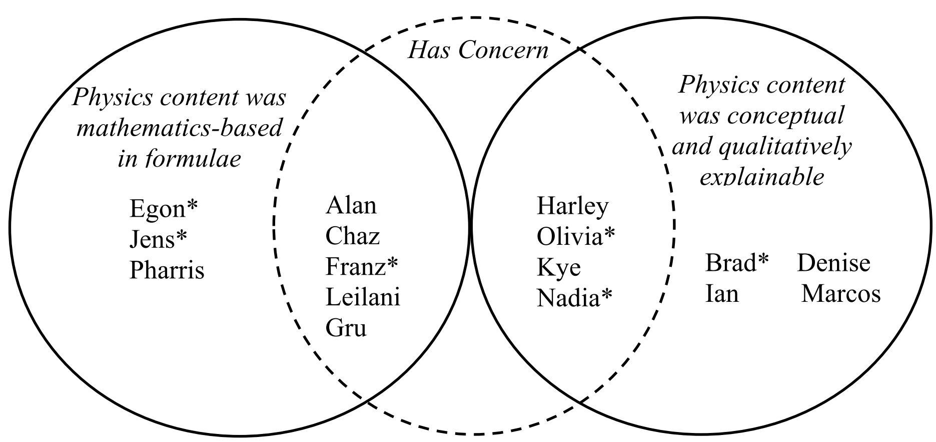
> I think there's too much stuff in there. I think they cut out some very key, fundamental, core stuff. When I say that I think there's too much stuff in there it's because that fundamental core stuff that they cut out, I still teach it. (Chaz)

Later in the interview, Chaz said, "the [1992] document didn't have as much stuff in it as [the 2017 document] does. [The 2017 document] has a lot more big ideas in it than the [1992] one did." Chaz interpreted some of these big ideas to include aspects that were not listed in the indicators (such as graphing kinematics within the outcomes on motion) which required more time to teach than was available in a semester. Alan too felt that there was too much content in the 2017 curriculum document but admitted this was because he gravitated toward mathematically oriented physics even when the indicator did not specify the need for any mathematics. To Alan and Chaz, both of whom believed that physics knowledge was mathematics based, there was a lot of necessary content implied within those outcomes that could be taught without mathematics and this implied content made it difficult to complete this document in one semester.

4.3.2.5. Stage 4 (Consequences) Concern, Course Variation in Physics 30 Across Saskatchewan. In comparing teachers who reported this concern with their expressed beliefs about the content of physics knowledge, no clear pattern was evident in this study. Figure 26 shows that teachers on both sides of the continuum of epistemic beliefs about the content of physics knowledge communicated concerns about the variation in Physics 30 classrooms across Saskatchewan. As viewable on Table 14, teachers concerned about course variation in Physics 30 were distributed across the continuum of epistemic beliefs about the content of physics knowledge. This included three teachers (Alan, Franz, and Chaz) represented near the extreme end of believing that physics knowledge was mathematics oriented, two teachers (Leilani and Gru) represented nearer neutral but believing that physics knowledge was mathematics oriented, one teacher (Nadia) represented nearer neutral but believing that physics knowledge was conceptual, and three teachers (Kye, Harley, and Olivia) represented near the extreme end of believing that the content of physics knowledge was conceptual. A pattern was not apparent

Figure 26

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About Course Variation in Physics 30 Courses Across Saskatchewan



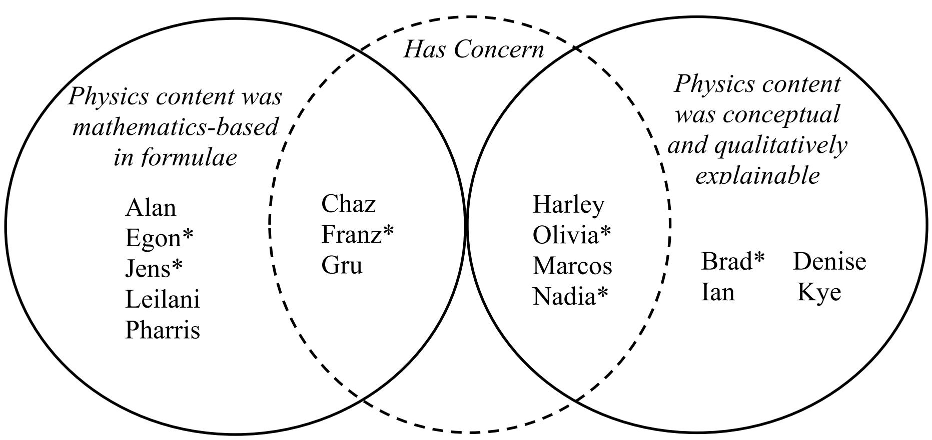
*indicates teacher is not accredited in physics

when considering teachers' beliefs about the content of physics knowledge and whether they reported concerns about course variation in Physics 30 classrooms across Saskatchewan.

4.3.2.6. Stage 4 (Consequence) Concern, Support for New and Non-Science Trained Teachers. Figure 27 shows that teachers on both sides of the continuum of epistemic beliefs about the content of physics knowledge reported concerns about the variation in Physics 30 classrooms across Saskatchewan. As viewable on Table 14, teachers concerned about support for new and non-science trained teachers were distributed across the continuum of epistemic beliefs about the content of physics knowledge. Participants with these concerns ranged from nearer the extreme end of believing that physics knowledge was mathematics oriented (Franz and Chaz) to the near the extreme end of believing that the content of physics knowledge was conceptual (Harley, Olivia, and Marcos). In this study, it appeared that teachers' beliefs about the content of physics knowledge were not connected to whether they reported concerns about support for new and non-science trained teachers.

Figure 27

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About Support for New and Non-Science Trained Teachers



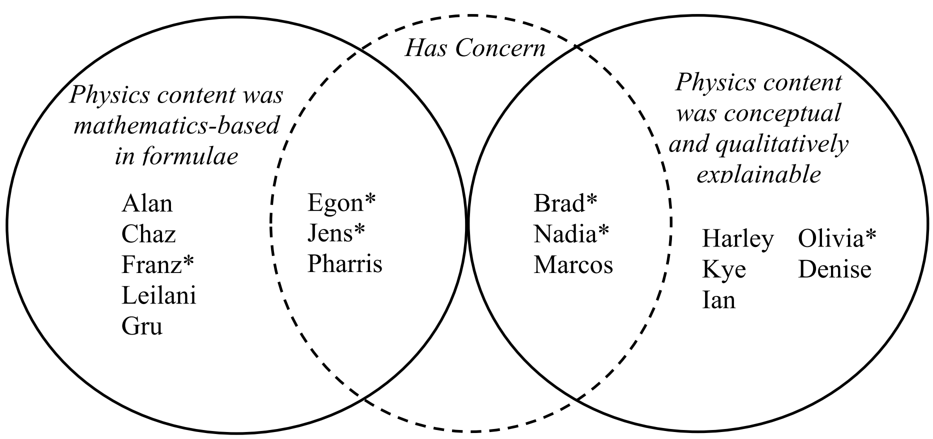
*indicates teacher is not accredited in physics

4.3.2.7. Stage 4 (Consequence) Concern, The Content is Too Theoretical (or Not Rigorous Enough). Three teachers who believed that physics knowledge was mathematically oriented and three teachers who believed that physics knowledge was qualitative and conceptual expressed the concern that content was too theoretical (or not rigorous enough); this is shown in both Figure 28 and Table 14. Looking at Table 14, it would appear that teachers expressing concerns that the content is too theoretical (or not rigorous enough) in the 2017 curriculum document are relatively well distributed. However, no teacher represented as being near the end of the continuum depicting the belief that physics knowledge was mathematics-based communicated this concern; these teachers would have existed near the far-left end of Table 14.

One of the first interviews that I conducted was with Alan who was coded as believing that the content of physics was mathematically oriented and not conceptual (see Figure 11 or Table 14). Alan even went so far as to claim that the qualitative side of physics was a "lower level" of learning than the quantitative side. However, Alan did not discuss concerns that this

Figure 28

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About The Content Being Too Theoretical (or Not Rigorous Enough)



*indicates teacher is not accredited in physics

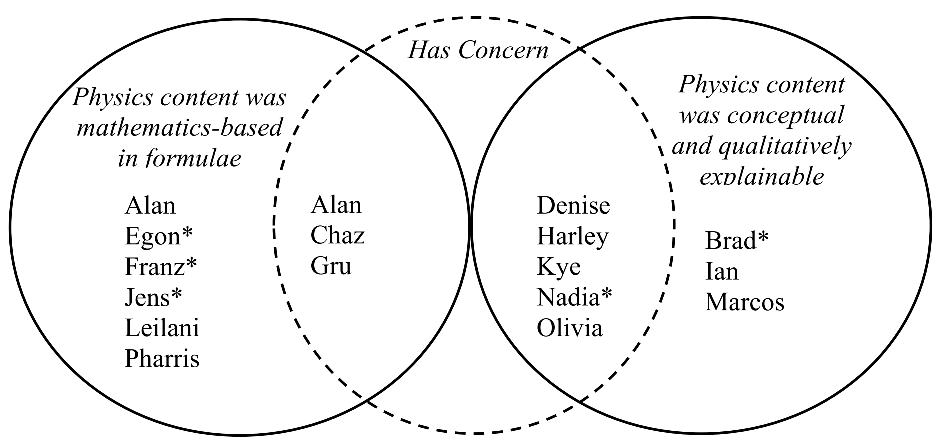
document was too theoretical. This may have been because he applied mathematics to content which did not necessarily require mathematics. For example, Alan said that he “even [threw] in equations that aren’t in the curriculum,” such as teaching some mathematics behind quantum mechanics. The 2017 Physics 30 curriculum document included an indicator under the modern physics outcomes that alluded to this use of mathematics, “determine Planck’s constant experimentally or using simulations […]” (Saskatchewan Education, 2016, p. 32), but it did not require (or list) any equations to be used. Alan was an accredited teacher and, as such, could interpret the overarching outcome of “analyze the importance of relativistic principles and quantum mechanics in our world” (Saskatchewan Education, 2016, p. 32) to include a mathematical understanding if he felt that met the outcome. This flexibility allowed Alan to read the document through his filter of believing that the content of physics knowledge was based in mathematics.

Pharris, on the other hand, also believed that the content of physics knowledge was mathematically oriented (although he was placed closer to neutral on the continuum than Alan, see Table 14) but, unlike Alan, he expressed the concern that this document was too theoretical. Pharris expressed concerns about teaching the outcomes in the fields unit claiming these outcomes lacked the rigour of mathematical problem solving (or “intense problem solving” as Pharris described it) found in the other outcomes (see *4.2.3.3. The Content is Too Theoretical (or Not Rigorous Enough*). When reading this document, Pharris, like Alan, believed that mathematics provided legitimacy (and rigour) to a physics course but, unlike Alan, Pharris did not perceive the need to teach mathematics within the new outcomes of the 2017 document.

4.3.2.8. Stage 4 (Consequence) Concern, Students Were Unprepared for the Content in Physics 30. In this study, no connection was apparent between teachers' beliefs about the content of physics knowledge and whether they reported concerns about students being unprepared for the content in Physics 30. Figure 29 shows that teachers on both sides of the continuum of epistemic beliefs about the content of physics knowledge communicated these concerns. As shown in Table 14, teachers concerned about students being unprepared for the content Physics 30 were distributed across the continuum of epistemic beliefs about the content of physics knowledge. Ranging from nearer the extreme end of believing that physics knowledge was mathematics oriented (Alan and Chaz) to the near the extreme end of believing that the content of physics knowledge was conceptual (Harley, Olivia, and Kye). Given this relatively even distribution, it would appear that communicating this concern was not connected to teachers' beliefs about the content of physics knowledge.

Figure 29

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About Students Being Unprepared for the Content in Physics 30

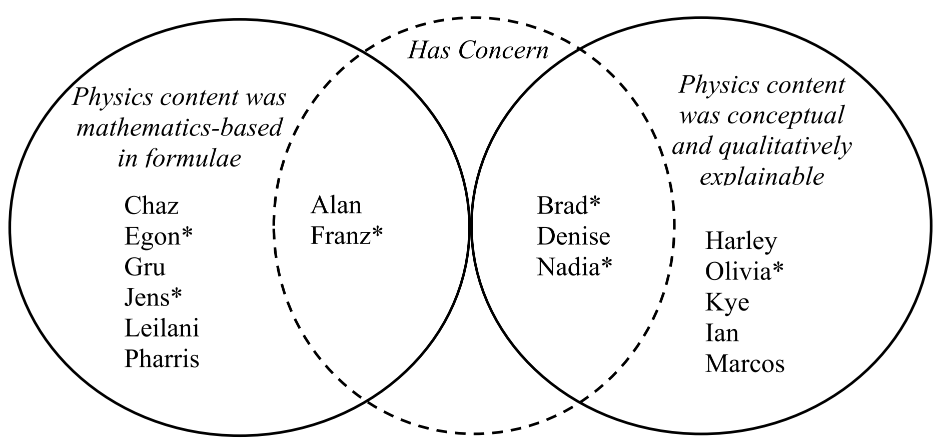


*indicates teacher is not accredited in physics

4.3.2.9. Stage 5 (Collaboration) Concern, How Were Other Teachers Teaching Physics 30? Teachers' beliefs about the content of physics knowledge did not appear to be connected to whether they reported concerns about how other teachers were teaching Physics 30. Figure 30 shows that teachers on both sides of the continuum of epistemic beliefs about the content of physics knowledge communicated these concerns. As shown in Table 14, teachers concerned about students being unprepared for the content of Physics 30 were distributed across the continuum of epistemic beliefs about the content of physics knowledge with only one or two teachers in each area of the continuum (as identified in Figure 11) reporting these concerns. Given this relatively even distribution, I interpreted this pattern as suggesting that this concern was not connected to teachers' beliefs about the content of physics knowledge.

Figure 30

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About How Other Teachers Were Teaching Physics 30

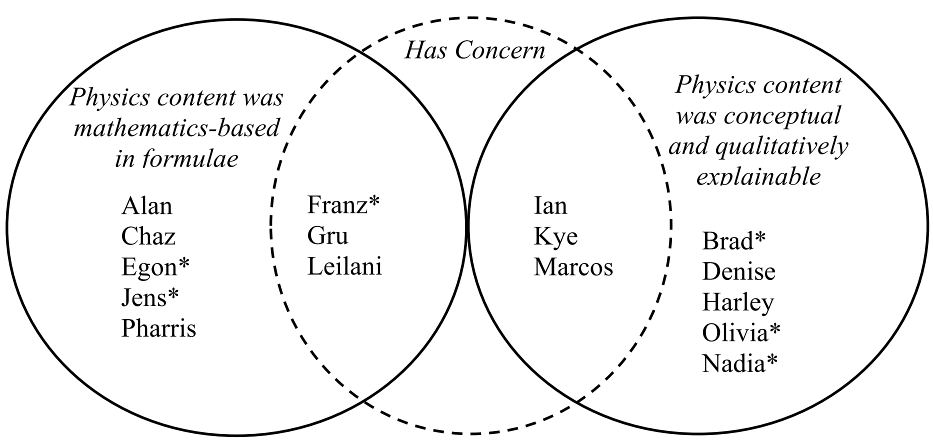


*indicates teacher is not accredited in physics

4.3.2.10. Stage 5 (Collaboration) Concern, Resistance Among Other Teachers. There was no apparent pattern when comparing teachers who reported concerns about resistance among other teachers with their expressed beliefs about the content of physics knowledge. As shown in Figure 31, this concern was expressed by three teachers on each side of the continuum of epistemic beliefs about the content of physics knowledge. In viewing teachers' beliefs along a continuum, as in Table 14, one teacher (Franz) represented nearer the extreme end of believing that physics knowledge was mathematics oriented expressed these concerns. Also, two teachers (Gru and Leilani) represented nearer neutral but believing that physics knowledge was mathematics oriented expressed these concerns. Similarly, one teacher (Brad) represented near the extreme end of believing that physics knowledge was conceptual expressed these concerns as did two teachers (Nadia and Denise) represented nearer neutral but believing that physics knowledge was conceptual. Given this distribution, it would appear that these teachers' concerns

Figure 31

Venn Representation of Epistemic Beliefs about the Content of Physics Knowledge and Concerns About Resistance Among Other Teachers



*indicates teacher is not accredited in physics

about resistance among other teachers were not connected to their epistemic beliefs about the content of physics knowledge.

4.3.2.11. Summary of Connections between Beliefs about the Content of Physics and Concerns. In this study, eight teachers communicated the belief that physics knowledge was rooted in mathematics and eight teachers communicated the belief that physics knowledge was qualitative and conceptual. On each side of the continuum of epistemic beliefs about the content of physics, teachers were distributed between more neutral and extreme positions. In considering teachers' concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, several concerns were identified as potentially connected to teachers' epistemic beliefs about the content of physics knowledge: (a) lack of confidence in understanding content in the 2017 Saskatchewan Physics 30 curriculum document that was not part of the 1992 document, (b) effectiveness in preparing students for a standardized exam, (c) a lack of available resources and instruction on implementation, and (d) there was too much content to teach in one semester.

Six teachers expressing the belief that physics knowledge was conceptual and qualitative voiced concerns about a lack of confidence in understanding content in the 2017 Saskatchewan Physics 30 curriculum document that was not part of the 1992 document. These teachers were distributed across the conceptual-physics side of the continuum of epistemic beliefs about the content of physics knowledge. Concerns about lack of confidence in understanding the content added to Physics 30 in the 2017 curriculum document was also voiced by three teachers placed near neutral of the continuum of epistemic beliefs about the content of physics knowledge but communicating the belief that the content of physics knowledge was based in mathematics. No teacher placed near the end of the continuum representing those believing that physics knowledge was based in mathematics voiced concerns about a lack of confidence in understanding the content added to Physics 30 in the 2017 curriculum document. This suggests that teachers believing that the content of physics knowledge was (at least in part) conceptual in this study were more likely to express concerns about understanding the content added to the 2017 curriculum document than those teachers represented nearer the extreme end of believing that the content of physics knowledge was mathematical.

Only the three non-accredited teachers who believed that the content of physics knowledge was conceptual and qualitative expressed concerns about their effectiveness in ensuring student success on the Physics 30 provincial exam. Non-accredited teachers communicating the belief that physics knowledge was mathematically oriented did not express concerns about preparing their students for the Physics 30 provincial exam. Teachers expressing this concern discussed their frustration with having to prepare students for an exam which focused on the use of equations and mathematics.

A potential connection was evident between teachers' epistemic beliefs about the content of physics knowledge and teachers' concerns about a lack of instructions and resources in this study. Teachers across the continuum of epistemic beliefs about the content of physics knowledge were concerned about how much time to allot teaching individual curricular outcomes. Mathematically oriented teachers' concerns were focused on a need for resources to teach the "abstract" or "esoteric" ideas in the 2017 document. Brad, Nadia, and Olivia all communicated the belief that physics knowledge was qualitatively explainable and were concerned about a lack of instructions and resources as well; these teachers' concerns were focused on a lack of resources to alleviate time-management pressures (i.e., course planning). Brad, Nadia, and Olivia, along with three of the five mathematically oriented teachers, were all non-accredited. Only two accredited teachers communicating the belief that physics content was mathematically oriented reported concerns about a lack of resources to help them teach the 2017 Saskatchewan Physics 30 curriculum document.

Teachers at the extreme ends of the continuum of epistemic beliefs about the content of physics knowledge in this study were more likely to express concerns about the 2017 curriculum document having too much content to teach. Harley and Olivia, two teachers represented near the end of the continuum indicating that the content of physics knowledge was conceptual and qualitative, were concerned that they ran out of time teaching Physics 30 because they had to spend much of their course dedicated to mathematics, not physics, instruction. Alan, Chaz, and Franz were represented on the other end of this continuum, strongly believing that the content of physics knowledge was based in mathematics, and were concerned that there was a lot of missed content implied within the 2017 curriculum document, specifically a lot of mathematical concepts. Teaching this implied content increased the time needed to teach each outcome, meaning there was too much information for them to teach in one semester. The teachers placed at both extremes of the continuum of epistemic beliefs about the content of physics knowledge connected their concerns about the 2017 document having too much content to mathematics instruction, even if both groups had different perspectives on this concern.

Six teachers who communicated that—at least in some part—physics knowledge was qualitative expressed concerns about the content in the 2017 curriculum document being too theoretical; three of these teachers were represented near neutral but communicating the belief that physics knowledge was mathematically oriented and three teachers were distributed between neutral and the extreme belief that physics knowledge was qualitative. No teacher represented near the end of the continuum indicating that physics knowledge was based in mathematics reported the concern that the content in the 2017 curriculum document was too theoretical (or not rigorous enough). Specifically, Alan, Chaz, and Franz, who were all represented near the extreme belief that the content of physics knowledge was based in mathematics, were not concerned about the content being too theoretical but were concerned about having too much content in this document because of the necessary mathematics they considered to be implied in each outcome.

4.3.3. Summarizing Connections Between Teachers' Epistemic Beliefs about Physics Knowledge and Their Concerns with the 2017 Saskatchewan Physics 30 curriculum

According to the data analysis, there were some potential connections between teachers' epistemic beliefs about physics and the concerns they had regarding the 2017 Saskatchewan Physics 30 curriculum document. Concerns regarding this curriculum document were investigated in relation to teachers' epistemic beliefs about the content of physics knowledge and the source of physics knowledge since teachers largely concurred about the certainty and coherence of physics knowledge and this consistency made it difficult to determine clear patterns. The connection, as I had interpreted from the data, between teachers' epistemic beliefs about the source of physics knowledge and concerns regarding the 2017 Saskatchewan Physics 30 curriculum document included:

- only teachers communicating the belief that physics knowledge was discovered but recognizing that invention also contributed to the development of physics knowledge expressed concerns about a lack of confidence in understanding the content added to the 2017 curriculum document.

Evident connections, as I interpreted from the data, between teachers' epistemic beliefs about the content of physics knowledge and concerns regarding the 2017 Saskatchewan Physics 30 curriculum document included:

- no teacher represented near the extreme of believing that the content of physics was mathematically oriented reported concerns regarding a lack of confidence in understanding the content added to the 2017 curriculum document;
- solely non-accredited teachers who believed that the content of physics knowledge was conceptual and qualitative expressed concerns regarding preparing their students to write a provincial exam. Teachers indicated that these concerns were due to the conflict in connecting the conceptually oriented curriculum document and the mathematics-heavy provincial exam;
- teachers across the continuum of epistemic beliefs about physics content reported concerns regarding a lack of instruction and resources accompanying the 2017 curriculum document but the type of support wanted by teachers could be connected to their epistemic beliefs about the content of physics; and
- teachers represented near both extremes of the continuum of epistemic beliefs about the content of physics knowledge expressed concerns over the inclusion of too much content in this new curriculum document. Alan, Chaz, and Franz—the mathematics-oriented teachers reporting these concerns—were concerned about the mathematics content not explicitly included within the Physics 30 curriculum document. Harley and Olivia—the qualitative physics-oriented teachers reporting these concerns—were concerned about having to review mathematics when they wanted to focus on teaching the conceptual side of physics.

4.4. Results Summary

This chapter reported findings regarding teachers' epistemic beliefs about physics knowledge, teachers' concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, and potential connections between teachers' epistemic beliefs about physics knowledge and their concerns.

Teachers concurred about some epistemic beliefs about physics knowledge and were less in agreement about others. Findings indicate that teachers in this study unanimously communicated that physics knowledge was tentative and subject to change. One teacher, Nadia, communicated the epistemic belief that physics knowledge could be a collection of isolated ideas but the other 15 teachers communicated that physics knowledge was a system of coherent and connected ideas. Three teachers expressed the belief that physics was invented by humanity with only Ian, who was well versed in the philosophy of science, represented near the end of the continuum in this belief (see Figure 9). Teachers were evenly divided about whether the content of physics knowledge was mathematically oriented or qualitative and conceptual.

Teachers' concerns about the 2017 Saskatchewan Physics 30 curriculum document ranged from stage 2 (personal) concerns to stage 5 (collaboration) concerns. Most of teachers' concern themes were stage 4 (consequence) concerns. Two years after the first province-wide implementation of the 2017 Physics 30 curriculum document (as it was released in the fall of 2016 and revised in 2017) in Saskatchewan, teachers' concerns were varied but focused on their abilities to effectively teach, manage and implement this document, the potential and perceived consequences of this document, and how other teachers were teaching Physics 30 across the province.

Several connections between teachers' epistemic beliefs about the source of and content of physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document were identified. These included:

- only teachers who were placed nearer the centre of the continuum but believing that physics knowledge was discovered expressed concerns about a lack of confidence in understanding the content added to the 2017 curriculum document;
- teachers expressing the epistemic belief that physics knowledge was conceptual and qualitative (including those represented near neutral on the mathematics-based side of the continuum of epistemic beliefs about the content of physics) communicated concerns about a lack of confidence in understanding the content added to the 2017 curriculum document;
- concerns about an individual's ability to prepare students for the provincial Physics 30 exam were unique to non-accredited teachers communicating the epistemic belief that physics knowledge was conceptual and qualitatively explained;
- teachers' expressing concerns regarding a lack of materials and instruction with which to implement the 2017 Physics 30 documents reported different concerns depending on which side of the continuum of epistemic beliefs about the content of physics knowledge they were represented; and,
- only teachers near each extreme of the continuum of epistemic beliefs about the content of physics communicated concerns about having too much content to teach in the 2017 Physics 30 curriculum document and teachers at both ends of this continuum discussed these concerns as related to mathematics instruction in their physics classrooms.

Implications of these findings, as well as teachers' epistemic beliefs about physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, will be addressed in the next chapter.

CHAPTER 5: DISCUSSION

In this chapter, findings are interpreted and situated within the context of existing literature. Ways in which this study has furthered our understanding of teachers' epistemic beliefs about physics knowledge and their concerns regarding a mandated curriculum document change discussed. Each of the three research questions identified in Chapter 1 are explored and serve as the heading titles for each of their respective sections.

5.1. What were Saskatchewan Physics 30 Teachers' Epistemic Beliefs about Physics Knowledge?

Literature has identified that physics teachers do not often consider the philosophy informing their subject of instruction unless prompted by a specific reason (Erudran & Kaya, 2019; Mulhall & Gunstone, 2008). This study promoted philosophical discussions while inviting teachers to explore their epistemic beliefs about physics knowledge. In general, teachers believed that physics knowledge was a coherent and connected system of ideas that was subject to change. Most (13 of 16) teachers believed that physics knowledge was (at least somewhat) a representation of knowledge discovered from an external reality with three teachers describing physics as invented by humans as we interpret our world. Finally, teachers varied across the continuum representing teachers' epistemic beliefs about the content of physics knowledge; eight teachers communicated the belief that physics knowledge was conceptual (five near the furthest end of this side of the continuum) and eight teachers communicated the belief that physics knowledge was mathematics-based (three near the furthest end of this side of the continuum).

5.1.1. Beliefs about the Structure and Certainty of Physics

Most teachers (15 of 16) in this study believed that physics knowledge was coherent and connected (as scientists/physicists and experts on the philosophy and nature of science do) at least to some degree. All 16 teachers fell somewhere on the side of the continuum of epistemic beliefs about the structure of physics representing the belief that physics knowledge was coherent and connected. Nadia was an outlier and expressed the belief that physics knowledge consisted of somewhat isolated topics (as students do). Studies have found students—both in high school and university—frequently believe that physics knowledge consists of isolated topics, whereas physicists and scholars versed in the philosophy and nature of science typically believe that physics consists of a system of coherent and connected ideas (Halloun & Hestenes, 1998; Mäntäyla & Nousiainen, 2014; Moore, 2018). Nadia supported her beliefs with explanations connected to ideas included within the past and current physics courses taught in Saskatchewan. Physics 30, in Saskatchewan as in many science curriculum documents, was divided into separable units and topics, or, as Harley put it, "compartmentalized information". Nadia described physics as it was taught in school (as students see it) whereas other participants discussed physics as a discipline (as physicsts see it).

Kang and Wallace (2005) also reported the separation of 'knowing in a discipline' versus 'knowing in school' in their research. One of their research participants, Jerry, a science teacher, described 'real science' knowledge as differing from 'school science' knowledge, with the former being tentative and validated through inquiry and the latter as predetermined and rarely open to interpretation. Across numerous reviewed studies, Maggioni and Parkinson (2008) found that teachers distinguish school science—portrayed as pre-determined and unchanging—from 'real' science, which was subject to change. Correspondingly, this study found one teacher, Nadia, describing the discipline of physics as what Jerry might have called (and what Gru did call) 'school physics,' aligning her beliefs with those typically reported by physics students as opposed to aligning with experts (i.e., those knowledgeable about the philosophy and nature of science).

When considering teachers' epistemic beliefs about the certainty of physics knowledge, all teachers in this study communicated the epistemic belief that physics knowledge was tentative and subject to change. In science education, epistemic belief studies have claimed the belief that knowledge is tentative to be considered the view of the mature knower (Chevrier et al., 2019; Halloun, 1997; Halloun & Hestenes, 1998; Muis & Geirus, 2014; Tsai, 2006); it has also been claimed that this belief is consistent with physicists (Moore, 2018; Redish et al., 1998). Teachers agreed that physics knowledge was tentative with half of the teachers in this study adding the caveat that not all physics knowledge was likely to change. Many teachers were reluctant to agree that 'fundamental' knowledge would change. Some examples of fundamental knowledge given by teachers in this study were Newton's Laws and relativity. This study confirms the efforts of other educational researchers within the epistemic belief literature; Burbules and Linn (1991), Tsai (2006), and Sin (2014) all found science teachers claiming that science knowledge could change but that it was unlikely fundamental knowledge would change. Findings regarding teachers' epistemic beliefs about the certainty of physics knowledge align with previously reported studies—teachers believed that physics knowledge was (generally) tentative and subject to change.

5.1.2. Beliefs about the Source of Physics

13 of 16 teachers reported the belief that physics knowledge primarily existed in an external reality, waiting to be discovered. Most (11) of these teachers communicated that physics knowledge existed in an external reality, waiting to be discovered, but also recognized that this knowledge was explained by humans upon discovery. The epistemic belief that physics

knowledge was discovered from an external reality is more closely aligned with students than those of expert scientists (Deniz, 2017) and this belief contradicted the description of the nature of science described in the 2017 Saskatchewan Physics 30 curriculum document (Ministry of Education, 2017). This finding contradicts previous claims made by Halloun (1997), Halloun & Hestenes (1998), and Moore (2018), who each claimed that physics teachers could be assumed to hold epistemic beliefs about science knowledge which aligned with the epistemic beliefs of practicing scientists. Assuming (perhaps inappropriately) that teachers in this study were a representative sample, this finding may be cause for concern as previous writing in science education (e.g., Halloun, 1997; Halloun & Hestenes, 1998; Moore, 2018) has assumed that teachers' beliefs align with those of expert scientists when this may not always be the case.

Teachers may have communicated the epistemic belief that physics knowledge was discovered as a result of confusion between the convention of the discipline and the nature of knowing in physics. While it is certainly true that science (including physics) is empirically based, physics (and science) knowledge is a human construct (Abd-El-Khalick et al., 2017; Deniz, 2017; Hansson & Leden, 2016; Schizas & Psillos, 2019). Physics does not explain the world as it really is, but how we (as humans) perceive it to be (Gregory, 1988). Ian firmly believed that physics was invented by humanity, but he addressed this confusion by saying,

> Mother Nature is out there. Everywhere. She doesn't actually give a rip about how you describe her at all. We can ask her questions, she always answers. We have to be smart enough to interpret what that means but our interpretation is a convenient story that we tell ourselves so that we can continue to make good predictions rather than some sort of absolute truth about the universe that exists.

It would appear that many teachers in this study were mistaking the empirical nature of physics as negating the human-constructed nature of physics knowledge. To connect to Ian's explanation, most teachers in this study expressed that what they heard from "Mother Nature" was the knowledge of physics, when recent physicists, philosophers, and the Saskatchewan curricula would claim that physics knowledge was in the interpretation of what was heard.

Thirteen teachers believed that physics knowledge was discovered from an external reality and this contradicted the stated position in the Saskatchewan Physics 30 curriculum document regarding the source of physics knowledge. According to the 2017 Saskatchewan Physics 30 curriculum document, "science is a creative human activity," and "scientific development takes place within a social context [...] along with personal biases and the need for peer acceptance," (Ministry of Education, 2017, p. 13). This quotation, which explains science as a human endeavour (i.e., science is invented by humans), is part of the explanation regarding knowing in science located in the front-matter of the 2017 Physics 30 curriculum document. Many (13 of 16) teachers expressed epistemic beliefs in contradiction to the position of the 2017 curriculum document and this raises the question of whether practicing teachers deeply interact with the front matter of the curriculum document (where this position is explained). When discussing how the philosophy of science was better integrated into the 2017 curriculum document (when compared to the 1992 document) one teacher and I shared a few comments on the issue of the neglected front matter:

Ian: You mean the front half that no-one ever reads.

Interviewer: Yes, I do, which, I should not mean, but I do.

Ian: Well, but that's ultimately what happens.

Teachers were not directly asked whether they had read the front matter in these interviews, so I have no way of knowing if this was indeed the case. Still, it should be recognized that most teachers in this study held epistemic beliefs about the source of physics knowledge which contradicted the views stated within the 2017 Saskatchewan Physics 30 curriculum document.

This frequent variation in understanding of the source of physics knowledge might be remedied by reconsidering those requirements to teach physics in Saskatchewan. Anyone with a valid teaching certificate in Saskatchewan can teach any course—this means that teachers who teach physics can be (and often are) out-of-field; these teachers are considered to be non-accredited. Considering the accredited teachers to be physics specialists, there were still many of them expressing the belief that physics knowledge was discovered from an external reality (i.e., Chaz, Denise, Harley, Kye, Leilani, Marcos, and Pharris).

To be accredited to teach Physics 30 in Saskatchewan, teachers must have at least 12 hours of academic coursework in physics and nine hours in related areas plus one science methods course. Courses that can be used as physics coursework include astronomy, physics, and some engineering courses; related areas include mathematics and chemistry courses. To be accredited, physics teachers do not need to have had any formal education in the philosophy or nature of physics or science (unless this is covered as part of their science methods course). By having the requirements to be a 'subject specialist' reflect only the courses focused on content, the Saskatchewan Ministry of Education has communicated that content-knowledge is more important than knowing the philosophy and nature of one's subject. Should the Saskatchewan Ministry of Education require physics teachers to engage with the philosophy of their subject, they may be considered innovators since, as suggested by Galili (2018), Mulhall and Gunstone (2008), and Pospiech (2019), physics teachers are often not well-versed in the philosophy of their subject. The inclusion of the requirement of courses (or professional development) studying the philosophy and nature of physics into physics accreditation requirements might mitigate future miscommunication about the source of physics knowledge and add innovation to Saskatchewan's approach to physics teacher education.

As the majority of teachers in this sample communicated the belief that physics knowledge was discovered from an external reality, at least to some extent, I wonder about the impact this had on physics teaching practices across the province. Subscribing to the epistemic belief that physics knowledge was discovered from an external reality might hinder teachers from using constructivist teaching methods (Lohse-Bossenz, et al., 2019; Ponnock, 2017), including inquiry which is only one of three instructional methods explicitly encouraged in the 2017 Saskatchewan Physics 30 curriculum document (the others being science challenges and laboratory work). The Saskatchewan Physics 30 curriculum indicated that knowledge was constructed using models and emphasizes inquiry as a "philosophical approach to teaching and learning [...that is...] grounded in constructivist research and methods," (Ministry of Education, 2017, p. 11). Inquiry was mentioned forty-three times in the 44-page document and was described in three[18] of the four foundations of all Saskatchewan science curricula.

Recent studies (e.g., Enriquez, 2019; Leng et al., 2018; Lohse-Bossenz, et al., 2019; Ponnock, 2017) have reported that teachers with less expert-like epistemic beliefs (i.e., beliefs that oppose those of scholars versed in the nature and philosophy of science) are less likely to

[18] In "Foundation 3: Scientific and Technological Skills and Processes" on page 21 of the Saskatchewan Physics 30 document (Ministry of Education, 2017), the word *inquiry* is not formally included but they do discuss the phases of inquiry (questioning, creating and executing a plan, analyzing and interpretation) as described on pages 11 – 13 of the same document.

have constructivist teaching beliefs. Most teachers' in this sample subscribed to the epistemic belief commonly attributed to students: physics knowledge exists in an external (and knowable) reality. Given these subscriptions, I wonder if any teacher who believed that physics knowledge was discovered from a knowable reality might struggle to effectively model the processes that reflect constructivist approaches (which acknowledge that knowledge is created), such as inquiry, being requested by science education scholars (and the government)? For over 130 years those involved with physics education have supported the use of inquiry-type instructional methods, but the implementation of this method on a large scale has consistently failed (Huling, 2014; Otero & Meltzer, 2017; Meltzer & Otero, 2015); perhaps the answer to sustaining these instructional approaches lie in addressing teachers' epistemic beliefs about the source of physics knowledge?

Participants were not specifically asked about their preferred teaching methods, but one teacher did speak about her approaches to teaching physics. Harley was incredibly pro-inquiry and communicated the epistemic belief that physics knowledge was discovered with the caveat that physics knowledge is explained by humans after it has been discovered. Harley does indicate an opposition to those studies claiming that teachers with epistemic beliefs opposing experts of the philosophy and nature of science tended to shy from constructivist teaching methods (e.g., Enriquez, 2019; Leng et al., 2018; Lohse-Bossenz, et al., 2019; Ponnock, 2017). Teaching practices were not a focus of this study; whether teachers communicated the belief that physics knowledge was discovered from reality and were able to effectively model constructivist learning, as expected by the 2017 Saskatchewan Physics 30 curriculum document could be an interesting future study.

5.1.3. Beliefs about the Content of Physics

"You can teach physics like a math teacher or you can teach physics like a science teacher," (Harley).

The separation of mathematics and physics has been noted in physics education research (Brahmia, 2014; Hammer, 1994; Turşucu et al., 2017), and this study corroborated these claims that teachers describe mathematics and physics as separate disciplines. Scholars such as Elby (2011), Hammer (1994), and Pospiech (2019), have described physics as consisting of both conceptual, qualitative understandings and mathematical explanations. In this study, teachers naturally described mathematics and physics as separate entities. Given this separation, I suggest that future investigations explore the impact this voiced separation might have on the instruction of physics across the province of Saskatchewan, building on works such as Mulhall and Gunstone (2008); how do mathematics and physics work together (and separately) in a teachers' eyes and their classroom?

Eight teachers communicated the belief that physics knowledge was mathematically oriented and eight teachers communicated the belief that physics knowledge was rooted in a conceptual, qualitative understanding of the world. This split suggests that variation might occur in physics classrooms across the province. In Saskatchewan, the grade 12 physics (Physics 30) curriculum (Ministry of Education, 2017) provides nine overarching outcomes that can be met in any way the teacher deems necessary (indicators are given as suggestions of ways these outcomes might be met). With such an open curriculum, having teachers distributed across the continuum of epistemic beliefs about the content of physics suggests that students across the province might be having different experiences of physics education.

Students often hold those beliefs emphasized by their teachers (Muis, 2008), and students' physics education drives how the public sees the subject area. With students experiencing different beliefs about the content of physics knowledge, no teacher can ensure students outside of their classroom get 'the right' physics education since each teacher will define the 'right' education reflective of their own epistemic beliefs about physics knowledge, as evidenced by Alan and Harley's claims in *4.2.3.1. Course Variation Across the Province.* Even when those who produce curriculum documents have a specific orientation regarding physics as mathematically oriented or as qualitative explanation, teachers are more likely to enact a curriculum with their beliefs as opposed to those of any prescribed curriculum document (Lantz & Kass, 1987). Variance in the emphasis of mathematics in physics in Saskatchewan Physics 30 courses was likely to occur given teachers' variable epistemic beliefs about the content of physics knowledge.

Unlike the other areas of epistemic beliefs about physics knowledge, experts (i.e., practicing scientists) do not subscribe to one side of the continuum representing epistemic beliefs about the content of physics knowledge; "some [physicists] deem their subject overly mathematical [yet] others think it is mathematically sloppy," (Musser, 2019, p. 30). Similarly, teachers in this study were represented across the continuum of epistemic beliefs about the content of physics knowledge. Using mathematics does not oppose the understanding of physics concepts in the physics classroom, the two work together (Pospiech, 2019). Therefore, it is important teachers are aware of both aspects of this area of epistemic beliefs and present a duality of views (McComas et al., 1998).

After speaking with these sixteen teachers, I am very interested in pursuing research that investigates, what Pospiech et al. (2019) refer to as, teachers' views on the role of mathematics in physics. When asked whether physics was mathematically oriented or concept-based, a few teachers (Chaz and Franz) began their explanation by drawing a representation of how mathematics fits within all of the sciences. Similar explanations of representations came from other teachers (Brad and Harley). Given that some teachers were drawn to representing mathematics in physics, that physicists have not agreed on the role of mathematics in physics, and that teachers in this study indicated they could separate what was mathematics and what was physics, I am quite curious about teachers' representations (and understandings) of the role of mathematics in physics, particularly as visualized by both physics-trained and non-physics trained teachers. Studies of this nature could provide valuable insight into the education offered to both in-service and pre-service physics teachers.

5.2. What were Saskatchewan Physics 30 Teachers' Concerns about the 2017 Physics 30 Curriculum Document?

Teachers reported many concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, it's content and implementation. These concerns focused on personal effectiveness and managing the implementation of the 2017 curriculum document as well as the consequences teachers perceived as a result of this new curriculum. Some teachers also expressed concerns regarding a lack of collaboration and connection with other physics teachers.

Looking across the stages of concern in which teachers' concerns lay, and the themes of concern within each stage, four areas of concern can be considered representative for this study. First, teachers were concerned about the increased importance of their own interpretation that came with the 2017 document and the new outcome-indicator format (when compared with the 1992 curriculum document). Other areas included concerns about the sequencing of science and mathematics courses in grades 10–12 in Saskatchewan, teaching the content added to Physics 30 in the 2017 curriculum document, and feelings of isolation.

Teachers' concerns in this study were context-specific but have also been documented in the (thin) literature investigating concerns regarding curriculum change in science education. The exception to this documentation was teachers' feelings of isolation which was not evident in the literature about teachers' concerns regarding science curriculum change but has been documented in studies investigating physics teacher isolation and engagement in professional development (e.g., Kelly & Sheppard, 2010; Nehmeh & Kelly, 2018; Tesfaye & White, 2012). Findings from this research contribute a Western-Canadian perspective to the literature about teachers' concerns regarding the implementation of new senior science curricula.

5.2.1. Concerns about Increased Interpretation

Teachers reported concerns regarding their increased responsibility for interpreting the 2017 Saskatchewan Physics 30 curriculum, particularly when compared to the 1992 document. First, the misaligned epistemic orientations of the curriculum document and provincial exam were frustrating for teachers. I recommend this misalignment be addressed and the epistemic aims of the provincial exam made clearer for Saskatchewan teachers. Second, teachers communicated varying concerns about teaching all of the content in the 2017 curriculum document and these concerns were connected to their interpretation of the curriculum document. Third, teachers were concerned about the level of support offered alongside the 2017 curriculum document for new teachers and non-science teachers who were teaching Physics 30. Finally, teachers were concerned about the classroom variation across Saskatchewan they perceived as a result of the more-open curriculum document (when compared to the 1992 curriculum document). Given these concerns, I suggest that further research be conducted into Canadian physics teachers' views on the purpose of curriculum documents. As the 2017 Saskatchewan Physics 30 curriculum document gave less specific direction on the content and topics to be covered than the 1992 Physics 30 curriculum document, teachers were concerned about how this increased interpretation would impact the implementation of this document.

At the stage of personal concerns, teachers' concerns connected to the increased interpretation required of them to implement this document focused on whether they were able to prepare students to write the provincial exam, that is, how to reconcile the 2017 curriculum document with standardized assessment. Teachers in this study were concerned with divining what content in the more-open 2017 curriculum document would be assessed (and how it would be assessed) on the provincial exam. Both Wallace and Priestly (2017) and Fischer et al. (2019) had science teachers (in Scotland and the United States of America respectively) express similar concerns when preparing students for standardized exams from new (and more open) curriculum documents. Further, teachers in my study corroborate scholars such as Abadie and Bista (2018), Gabby et al. (2017) and Ryder et al. (2014) when they claim that disconnect between curricula and standardized exams is frustrating for teachers. This concern was identified within the literature review (see *2.3.3.3. Reconciling Intended Curricula with Assessment Practices*) as one of three common concerns about new science curricula reported by science teachers.

The 2017 Saskatchewan Physics 30 curriculum document gave much more room for teachers to make professional decisions about how and what to teach. Unfortunately, this was "useless" (as Franz claimed) to those teachers preparing students for a provincial exam. Teachers having to prepare students for a provincial exam gravitated to the "testable" (as Brad called them) indicators which focused on the use of equations (according to Olivia) and simple problem-solving. The cultural, nature of science, and socio-scientific focused outcomes would be easier to ignore when preparing students for a provincial exam because, as Stadermann and colleagues (2019) claimed, these areas are much more difficult to assess with a standardized exam since there is often no single correct response. The 2017 Saskatchewan Physics 30 curriculum document stressed the construction and application of scientific content as one of four goals of science education; the other three goals focus on the nature of science, interactions between science and our world, and the development of positive attitudes and scientific skills through inquiry. These other three goals are not as easily measured with a multiple-choice exam (as the provincial exam is offered), and, thus, could perceived by teachers as less likely to appear on the provincial exam. This was confusing for teachers; the curriculum was telling them one story about physics and the provincial exam requiring they tell another (to prepare students). This study indicates a need to ensure that provincial exams are better aligned with the curriculum document, as suggested in other studies (Abadie & Bista, 2018; Gabby et al., 2017; Stadermann et al., 2019), and that this alignment be made clear to teachers to alleviate personal concerns regarding the interpretation of this curriculum document.

Teachers were concerned about teaching all of the content in the 2017 Saskatchewan Physics 30 curriculum document. This concern was often connected to how teachers interpreted the outcomes and indicators within this curriculum document. Take the concerns of Chaz and Olivia, both teachers reported that the new curriculum document left out some aspects, whether it be “missing core content” (Chaz) or that there were a large number of ideas implied by one simple outcome (Olivia). Both Olivia and Chaz spoke to the outcomes (and content) within the 2017 curriculum document as it was being interpreted by them, not as it was written. These interpretations were, I contend, connected to an epistemic filter (as described by Fives & Buehl, 2012 and Wallace & Priestly, 2017) with which each teacher interpreted the curriculum document. It is because of this filter that—if a government wants to ensure a curriculum is implemented as intended—teachers need curriculum documents to indicate which topics are important to be taught and identify those topics that are tangential to clarify how deeply a topic should be covered in a course (Davis et al., 2006). Indicators were provided in the 2017 curriculum document to showcase the depth to which teachers should explore each outcome in Physics 30, but, according to teachers in this study, the expected depth of indicators would have been beneficial when planning their course.

Teachers' concerns about teaching all of the content in this curriculum revealed a further question to be posed; what is the purpose of a curriculum document for practicing teachers? Is the curriculum document a checklist of content to be taught in its entirety? If this is the case, it is of no surprise that the myth of coverage nagged at these teachers. The Physics 30 document claimed, "this curriculum provides the intended learning outcomes that Physics 30 students are expected to achieve in science by the end of the course," (Ministry of Education, 2017, p. 3), with the indicators providing an idea of the breadth and depth required to show achievement of each outcome. Teachers saw indicators as also requiring interpretation (as evidenced by Olivia). Without specific guidelines and curricular materials used to guide teaching, I argue that this curriculum document could not be used as a checklist of topics to be taught but, rather, that it told the story of physics (as Ian put it) from a certain perspective. Hence, I would propose future studies investigate teachers' views on the purpose of curriculum documents, specifically with Canadian science teachers.

Third, teachers were concerned about the impact that the amount of interpretation caused by a less prescriptive format would have on new and non-specialist physics teachers. As shown in Appendix A, the 1992 Physics 30 curriculum document in Saskatchewan provided very detailed and specific content to be learned accompanied by an explanation of (and mathematics behind) the concept and proposed teaching activities. The 2017 curriculum document provided teachers with far less specific information, containing the entirety of its intended outcomes and indicators on nine pages (with plenty of white space). Teachers were concerned that this change in format was not designed to support the new teacher or the teacher with less formal training in physics, and, according to Gru, these were the people who needed the curriculum document to be specific. After all, new teachers often "lack adequate understanding of science content," (Davis et al., 2006, p. 624). This lack of understanding may convolute one's interpretation of the curriculum document, leaving new and non-physics trained teachers wondering exactly what was meant by each indicator. As Franz said, the prescriptive nature of the 1992 curriculum document "levelled the playing field" for teachers less familiar with physics content. Given the less prescriptive nature of the 2017 Physics 30 curriculum document, as compared to the 1992 document, teachers in this study were concerned about the abilities of new and non-physics trained teachers to effectively teach this course.

Finally, teachers were concerned about the consequence of classroom variation across the province of Saskatchewan given that the 2017 Physics 30 curriculum document left much more room for interpretation than the 1992 document. Again, this highlights the lack of clarity regarding the intended purpose of the curriculum document. Teachers were unclear about these intentions. I wonder, did those mandating this government curriculum document have a vision of what a Physics 30 course should 'look' like? If so, teachers' concerns about ensuring equality in the content of physics instruction across the province may be justified. Yet, understandings of what constituted the correct way of teaching physics varied based on teachers' epistemic beliefs about physics knowledge in this study; as this was the case, can consistency of content be ensured in Physics 30 classrooms across the province? For that matter, should consistency of content be ensured in Physics 30 classrooms?

Understanding of physics content is undeniably important but, in addition to teaching subject-specific content, scholars have been arguing for an increased emphasis on science literacy including the nature of science, STSE connections, and science thinking (Milford et al., 2010; Stadermann et al., 2019). The Saskatchewan Physics 30 curriculum called for classrooms to focus on these aspects of scientific literacy (Ministry of Education, 2017). However, teachers were concerned about ensuring that physics was learned ‘correctly’, evidenced by their concerns about variation in classrooms across the province. For some, correctly learning physics meant being able to tackle rigorous mathematics problems (e.g., Alan and Pharris) for others it meant learning deep conceptual connections in physics (e.g., Harley); are either of these the correct way of knowing physics? Irrespective of teachers’ epistemic beliefs about a correct way of knowing physics, teachers reported concerns about the increased interpretation required by teachers when implementing this Physics 30 curriculum document. I contend these concerns about interpretation pointed to an understanding of the curriculum document as a checklist of content to be covered in a semester rather than a document used to inform the philosophical underpinnings of a course and offer suggestions for content with which students might engage.

5.2.2. Concerns about Course Sequencing and Preparation of Students

The concerns under this header reflect those concerns about uncertainty regarding the direction of new science curricula identified in the literature review (see *2.3.3.2. Uncertainty*). Teachers were concerned about students’ preparation for Physics 30 given the resequencing of the science curricula in Saskatchewan (shown in Figure 3). Specifically, teachers voiced concerns about expecting kinematics to be taught (and learned) in Science 10 and that the content in Physical Science 20 was not connected to the content in Physics 30. Physics teachers were frustrated because these preparatory courses were often not taught by teachers with a background in physics. These concerns were then compounded by not being able to teach all of the content in Physics 30 because course time was sacrificed to review. Finally, some teachers expressed concerns about mathematics being disconnected from physics education and students struggling with the mathematics needed for Physics 30. To address these concerns, I suggest that teachers be consulted in revising the sequence of physics education in Saskatchewan[19] and that schools reconsider siloing their mathematics and physics courses to promote a more connected and contextual understanding of physics (Chaudhry, 2019; Eichenlaub & Redish, 2019; Watson, 2018).

The concepts moved to Science 10 that could be considered physics are listed under the unit "Force and Motion in our World" and focus on analyzing uniform motion, uniform accelerated motion, and exploring "the relationship between force and motion for objects moving in one- and two-dimensions," (Ministry of Education, 2015, p. 26) and this could include adding vectors in one- and two-dimensions, friction, and Newton's three laws of motion. In the previous curriculum documents, motion, forces and two-dimensional problems were contained entirely within the 1992 Physics 30 curriculum document. As discussed by Chaz and Denise, Physics 30 teachers were concerned that those concepts previously covered in Physics 30 were not taught well (if taught at all) by Science 10 teachers; Chaz attributed this to the fact that most Science 10

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[19] It is clear in the literature (Lyons, 2006; McConaghy, 1990; Molnar et al., 2019; Saskatchewan Teachers' Federation, 2018) that teachers have been involved in writing individual course curriculum documents in Saskatchewan. However, given these writings and my personal experience, it is unclear how deeply teachers are integrated into the sequencing of topics throughout the Saskatchewan science curricula. It is my understanding that this was the responsibility of the Ministry of Education.

teachers were not "physics people." Sheppard et al. (2020) found that the students of out-of-field physics teachers tended to be outperformed by students of physics specialists. Teachers in this study expressed the same concerns about non-physics specialists teaching physics in Science 10. In addition, students often took Science 10 in grade 10 and did not take Physics 30 until grade 12, leaving at minimum one full year between the two courses (at most two years). Consequently, these ideas expected in Science 10 were being taught (or at least reviewed) by their Physics 30 teachers.

Between Science 10 and Physics 30 was Physical Science 20, which was a contentious course for these teachers. As one example, Kye said Physical Science 20 was "a whole other kettle of fish [...] I don't think Physical Science 20 prepares [students] for Physics 30." Again, teachers expressed concerns about how well physics ideas were taught in Saskatchewan classrooms. Teachers indicated that Physical Sciences 20 was often taught by "chemistry people" and these teachers were not as well prepared to teach physics as they were to teach the four chemistry-specific outcomes. As a result, according to Marcos, the physics in Physical Sciences 20 could focus entirely on activities (instead of the ideas). This issue reflects the early 20th century movement in American physics education where a general sciences course (combining the physical sciences, physics and chemistry) was created. Critics of this type of combined course included the physicist Robert Milikan who claimed this general science course wasted students' time by teaching superficial understandings of these sciences (Meltzer & Otero, 2015). Teachers in this study reported similar concerns to those expressed by Milikan over 100 years ago. Teachers wanted to talk about Physical Sciences 20 (and their concerns regarding this document). Unfortunately, this was not a focus of my study but it is a topic that I suggest be revisited through future research.

Unlike the concepts in Science 10, teachers were less concerned about whether students thoroughly learned the physics outcomes in Physical Sciences 20 because this course was (as they saw it) less connected to Physics 30. Teachers identified the disconnect between the topics in Physical Sciences 20 and Physics 30; this was also an issue with the 1992 Physics 20 and Physics 30 courses. Physics is a logical and hierarchical discipline (Mäntäyla & Nousiainen, 2014; Wheelahan, 2010), and Saskatchewan Physics 30 teachers wanted the curricular sequencing of physics content to reflect this structure. As described by the National Research Council (2012), connecting the topics sequentially—also described as aligning topics—across science courses might better portray the coherent[20] and connected nature of science (and, consequently, physics). In this study, teachers believed that proper alignment of physics topics might better prepare students for Physics 30.

Finally, teachers in this study discussed the concern that students did not have the mathematical skills required to succeed in Physics 30. This was attributed to many factors including sequencing in the mathematics curriculum (Chaz and Olivia), the approaches used to teach the "new" mathematics curriculum (Harley), and the simple fact that students were not "good at math" (Olivia and Gru). As mentioned, the Science 10 curriculum document included outcomes about the concepts of motion in one- and two-dimensions and this implied that students learn about vector addition. To teach vector addition mathematically, students must

[20] Coherence in this sense was used to describe alignment (as is described by the National Research Council). However, it should be recognized that this use of the word is common when discussing curricula but it has been described as conflating coherence with correctness (Sikorski & Hammer, 2017). I tend to agree with Sikorski and Hammer when they claim that curricula should focus on providing students opportunities to seek coherence rather than coherence as being inherent in the organization of topics but use the term here as it is commonly used when discussing coherence in curricula.

know trigonometry. Teachers were unsure when trigonometry was learned (e.g., Chaz was certain it was in grade 11), but those familiar with the mathematics curriculum in Saskatchewan knew it was taught in both Mathematics 10 courses[21]. This poses a problem; what if a student takes Science 10 before Mathematics 10? Was it the responsibility of the science teacher to teach the mathematics concept of trigonometry to ensure students can learn vector addition? Does this mismatch in content progression contribute to students' struggles with mathematics (as Olivia and Gru raised) in Physics 30? Brahmia (2014) claimed that the abstract ideas in physics were made even more difficult to learn in high school because the mathematical skills required are taught in mathematics courses after they are introduced in science; this claim was corroborated by teachers in this study. I propose a few potential solutions to this issue: (a) educate science teachers on the sequencing of mathematics topics (and mathematics teachers on the sequencing of science topics requiring these skills)[22], (b) rearrange the mathematics (or science) curricula to align these topics or ensure they appear in a useful order (as implied by Brahmia, 2014), or (c) reconsider teaching mathematics and science as separate subjects (Watson, 2018).

What we call disciplines (i.e., mathematics or science or physics), is a human-defined construct (Barnes et al.,1996). Given this, I lean toward my third suggestion above and propose that schools might reconsider the teaching of mathematics and science as separate subjects. As I discuss at length in Watson (2018), mathematics and physics can be taught as one school subject.

[21] Saskatchewan mathematics courses were designed using the Western and Northern Canadian Protocol and reflect similar courses in these provinces. Saskatchewan students are required to take either Mathematics 10 Workplace or Mathematics 10 Pre-Calculus and Foundations. Typically, these courses are taken in a student's grade 10 year.

[22] I make this suggestion as a result of personal experience. I had the opportunity to teach all of the mathematics courses from grades 9 – 12 as well as Science 10, Physics 20, and Physics 30. Since I had knowledge of the sequencing of both sets of curricula (mathematics and science/physics), I was able to identify whether a student had indeed encountered a mathematical concept required in science before taking my science/physics course.

This may make the connections between mathematics and physics clearer for students, emphasizing how physics appears in the discipline (as opposed to 'school' physics as discussed in *5.1.1*). It may seem easier to educate teachers on the sequencing of other topics but I am unsure whether this would promote change within student learning; teachers would know when to introduce or review a topic from either mathematics or science, but this superficial change may not portray the depth of connection between physics and mathematics that students deserve. Hence, I recommend that high schools consider teaching science and mathematics together.

I know that proposing the integration of physics and mathematics courses is not without its limitations. First, I recognize that combining mathematics and science could promote similar issues to the combining of physics and chemistry; combining courses might lead to a superficial understanding in both subjects (Meltzer & Otero, 2015). A combined course would require teachers to be sufficiently knowledgeable in mathematics as well as physics to teach both subjects. This is easy for me to propose since I am accredited to teach both subjects in Saskatchewan but this is not always the case. Second, I recognize that proposing a complete overhaul to the education system by combining mathematics education into physics or other sciences is radical. Educational change is not easy, nor is it quick, particularly when it is teachers driving the change (Fullan, 2016). One small step in this direction could be offering currently existing courses together, as suggested by Chaudhry (2019), with a teacher prepared to teach both physics and mathematics. This interdisciplinary approach could one day make way for the integration of mathematics and science courses, potentially addressing teachers' concerns of students lacking preparation in the mathematical skills necessary for Physics 30 in Saskatchewan.

5.2.3. Concerns about Content

Similar to those concerns discussed in the literature review (see *2.3.2.1. Content Changes*), teachers in this study reported concerns about the changes in content from the 1992 curriculum document to the 2017 curriculum document. Many of the concepts included in the 2017 Saskatchewan Physics 30 curriculum document were present in the 1992 document including forces and motion (focused on uniform and uniform accelerated motion) and conservation laws (focused on energy and momentum); these made up four of the eight physics-content specific outcomes in the 2017 Physics 30 curriculum document. However, as highlighted by teachers, the modern physics and fields outcomes were less familiar and were areas of concern for teachers. This suggests that teachers could have benefitted from targeted support (through professional development or resources) in learning and teaching these topics.

Teachers were concerned whether they would be able to effectively teach the content added to Physics 30 in the 2017 curriculum document. This stage 2 concern was expressed by nine teachers in this study. Teachers were concerned with teaching the topics new to Physics 30 in the 2017 curriculum document: fields and modern physics. Supporting previous work in this area (Borgerding et al., 2013; Christou et al., 2004; Lowe & Appleton, 2015), this study showed that when teachers perceive themselves as inadequately prepared to teach new content they are likely to be uneasy teaching these topics. As one's pedagogical content knowledge, or knowledge of teaching a subject such as physics, and pedagogical confidence in a subject area rely on the quality of their content knowledge (Kind & Chan, 2017; Wei & Chen, 2018), it was unsurprising to find teachers concerned about teaching content that was not within the 1992 curriculum document. Working with the 1992 Physics 30 course, these teachers would have developed strong understandings of those topics in this curriculum document and carried these understandings with them to teach the 2017 curriculum document. The topics new to Physics 30 in the 2017 curriculum document required teachers to learn (or re-learn) ideas in physics with which they were less familiar.

To deal with teachers' unfamiliarity with concepts, Borgerding et al. (2013) recommended offering professional development aimed at having teachers encounter new content in genuine science contexts. These opportunities were available for Saskatchewan teachers both nationally (e.g., EinsteinPlus offered by the Perimeter Institute for Theoretical Physics) and through locally developed activities (e.g., Chaz mentioned attending a session offered by the Department of Physics at a Saskatchewan university). Unfortunately, these opportunities were not accessible to all science teachers; for example, every two years EinsteinPlus selects up to 60 teachers across Canada and the globe to attend a one-week intensive professional development opportunity. The Perimeter Institute for Theoretical Physics also offers teachers free resources for teaching modern physics but, as Nadia highlighted, these resources are not specifically designed for the Saskatchewan Physics 30 curriculum. I recommend that those in charge of science curriculum development in Saskatchewan, at a minimum, consider providing professional development opportunities and suggest resources aimed at engaging teachers with the content new to Physics 30 (i.e., modern physics and fields). These opportunities should be provided for teachers to learn this content both through paid professional development days and personal preparation time.

To add new content to any course something has to be removed to make room and the removal of content from Physics 30 caused another aspect of concerns related to content. Egon and Marcos expressed concerns about removing measurable and tangible content (such as electric circuits) to replace it with abstract ideas (such as electric fields). Chaz was frustrated that what he considered to be fundamental content (i.e., motion) was removed from Physics 30.

These teachers were concerned about the removal of important content and, as they reported, their peers were concerned too. Science teachers often see themselves as guardians of content (Mulhall & Gunstone, 2008; Tytler, 2010) and often turn their focus to the topics they know when faced with unfamiliar topics (Le Fevre, 2014; Lowe & Appleton, 2015). The “old guard” (as Marcus labelled them) carried with them “baggage” (as Franz put it) from the old curriculum; after all, Physics 30 had been consistent in its format for 25 years. After that long, it was likely that Saskatchewan teachers had become comfortable in seeing Physics 30 a certain way and teachers were concerned about content that was removed. This concern would suggest that having clear messaging as to the reasons for removing certain units would have been beneficial to these teachers.

5.2.4. Concerns about Collegial Connections

As discussed in *4.2.4.1. How are others teaching this curriculum?* teachers were curious about how other people taught the 2017 curriculum document. This was the only overarching concern reported by teachers in this study but not identified in the literature review about science teachers’ concerns regarding new curriculum documents. The isolation felt by physics teachers was compounded by the fact that most interviewees were the only person in the building teaching physics. Teachers wanted to connect and discuss teaching Physics 30 with others;

> I would have been worried about [electromagnetism] for sure if I hadn’t and when I did teach it, I had taught it with somebody. I feel like that’s always the best professional development too when you work with someone to put [a course] together (Leilani).

Brad wanted to work with other physics teachers; “I’d like to get together to talk physics with other teachers but don’t have anyone here.” Brad, Denise, and Harley each reported that the opportunity to think about, and discuss, physics and the philosophy behind the discipline was a highlight for them as a participant in this study.

The isolation expressed by these physics teachers corroborates earlier studies examining the lives and engagement of physics teachers (Kelly & Sheppard, 2010; Nehmeh & Kelly, 2018; Tesfaye & White, 2012). In Saskatchewan, it was common to have a single physics teacher per school (and in some cases, one teacher would teach physics in multiple high schools in a single school division). Nehmeh and Kelly (2018), in their study with two introductory physics teachers, found that isolated physics teachers felt unsupported by their administration, ill-equipped to develop as physics teachers, and disconnected from their colleagues. In addition to this, Tesfaye and White (2012) found isolated physics teachers less likely to connect with science education professional organizations or attend professional meetings of science teachers. I can relate since, as a physics teacher, I—like many teachers in this study—was often surrounded by teachers more interested in professional development on teaching biology, chemistry, or general science topics at these professional meetings of science teachers. Isolation, it would seem, comes with the territory of being a physics teacher.

Physics teachers wanted to talk about the 2017 Physics 30 curriculum document but they were also keen to have someone else with whom they could ‘talk physics.’ Teachers appreciated being involved in this research because it gave them a chance to discuss things they thought about but had no one else with whom to discuss these ideas. Several teachers wished they had a community with whom they could discuss teaching, physics, and teaching physics. To achieve this community, similar to the recommendations made by Rushton et al. (2017), I propose a community focused on connecting physics teachers across Saskatchewan could offer the support desired by teachers.

Ideally, this community of physics teachers would be able to access synchronous connections for those able to attend as well as sustained, online connections to allow for access across the province. Tesfaye and White (2012) found isolated physics teachers less likely to connect with science professional organizations both face-to-face and online; I contend this problem may be solved by connecting teachers to a community specifically designed for those teaching physics, ideally led by an expert in physics education. This online community might allow for those connections sought by teachers in this study as well as provide a platform from which teachers' can gain exposure to the philosophy of, and their epistemic beliefs about, physics (an area often lacking as identified by Galili, 2018).

There is growing evidence to show that having teachers engaged in sustained reflection on their own epistemic beliefs may promote change (Brownlee, et al., 2017; Deniz, 2017), and it is important this teacher learning is rooted in research-based evidence (Guskey, 2009) and over enough time that change can occur (Darling-Hammond & Richardson, 2009; Desimone, 2011; Goddu, 2012). Still, to be considered an acceptable form of professional development, this type of community would require a shift in what counts as professional development (Korthagen, 2017). Those in charge of professional development would need to reconsider specific time/place situated professional development and consider professional development that happens in short bursts over an extended period; one hour thirty times per year meets a professional development requirement of 30 hours. Should a school division require proof of professional learning, those organizing the committee could easily provide some form of recognition noting the total interaction time of the participant. This type of professional learning would likely engage physics teachers more as they would have access to a community asking similar questions (Guskey, 2009; Darling-Hammond & Richardson, 2009) and sustained interactions with their fellow physics teachers, hopefully, lessening physics teachers' feelings of isolation.

5.3. Were there Connections between Teachers' Epistemic Beliefs about Physics and Their Concerns with the 2017 Saskatchewan Physics 30 Curriculum?

Findings from this study suggest that teachers' epistemic beliefs about physics knowledge were connected to some of their concerns expressed about the 2017 Saskatchewan Physics 30 curriculum document. First, concerns about teacher effectiveness were connected to both epistemic beliefs about the content of physics knowledge and the structure of physics knowledge. Second, concerns about support and resources were connected to epistemic beliefs about the content of physics knowledge. Finally, comparing teachers' concerns about the content being too theoretical with teachers' epistemic beliefs about the source of and content of physics knowledge showed potential connections.

5.3.1. Connecting Teachers' Epistemic Beliefs about Physics Knowledge with Concerns Regarding Teacher Effectiveness with the 2017 Physics 30 Curriculum and its Content

Literature has previously identified that teachers might express concerns regarding their personal inadequacies when teaching a new curriculum document (e.g., Ashraf, 2019; Borgerding et al., 2013). Physics teachers' efficacy regarding their instruction has been attributed to a lack of preparation in physics (Rushton et al., 2017; Sunal et al., 2015; Sunal et al., 2019b; Tesfaye & White, 2012), but findings from this study indicate that there may be a connection between teachers' epistemic beliefs about physics knowledge and their confidence in understanding the content added to Physics 30 in the 2017 curriculum document.

Epistemic congruence has been recently explored with high school science students (Pekrun et al., 2017; Muis et al., 2018; Rosman & Mayer, 2018). In these previously conducted studies, students were tasked with reading texts that were epistemically oriented to one view or another; students whose beliefs did not align with those expressed within the documents showed negative reactions, including anxiety and questioning. As curriculum documents have inherent biases, driven by the goals of a science curriculum, (DeBoer, 2000; Roberts 1982), and teachers view curriculum documents through their epistemic filters (Fives & Buehl, 2012; Schommer-Aikins, 2012; Wallace & Priestly, 2017), it would stand to reason that teachers could also have reactions based on the epistemic congruence (or incongruence) of their beliefs with those implied or explicitly stated within a curriculum document.

Findings from this study provide evidence that supports the assertion that teachers could also have reactions based on the epistemic congruence/incongruence of their beliefs with those implied within a curriculum document. For example, no teacher communicating the belief that physics knowledge was invented by humans, nor any teacher represented nearer the end of the continuum as believing that physics knowledge was based in mathematics, expressed concerns regarding their understanding of the content in the 2017 curriculum document. Additionally, none of the aforementioned teachers expressed concerns regarding the content in the 2017 Physics 30 curriculum document being too theoretical. As Ian put it, this was because the 2017 Physics 30 curriculum document told the story of physics as he saw it (i.e., he perceived that his beliefs about physics knowledge were epistemically congruent with this document). These teachers were comfortable with their capabilities to understand and teach the content in this document as they read it through their beliefs filter. This study indicates considering a warranted vein of epistemic congruence research with teachers in addition to the research being done with students. In this study, the epistemic orientation of the curriculum document was not defined (as this could be the topic of an entire doctoral study) but results would suggest that researchers investigate teachers' reactions as a result of epistemic congruence with documents with known epistemic orientations. Teachers, just as students, can have reactions driven by their epistemic congruence (or incongruence) with a document.

Literature has indicated that teachers with less experience with content introduced in a curriculum document are more likely to be concerned about teaching said content (e.g., Ashraf, 2019; Borgerding et al., 2013; Gabby et al. 2017). This study suggests that these concerns might also be connected to teachers' epistemic beliefs about the content of physics knowledge. Teachers communicating the epistemic belief that the content of physics knowledge was qualitative and conceptual were more likely to express concerns regarding their confidence in understanding the content new to Physics 30 in the 2017 curriculum document; this included those teachers communicating the belief that physics knowledge was mathematically oriented but acknowledging that conceptual and qualitative knowledge also informed physics. Teachers concerns about content in a new curriculum document also appear to be connected to their beliefs about the content of the subject of instruction.

To further the claim that teachers' epistemic beliefs about the content of physics knowledge were connected to teachers' concerns about understanding the content new to Physics 30 in the 2017 curriculum document, no teacher placed near the end of the continuum representing the belief that the content of physics knowledge was rooted in mathematics expressed concerns about understanding the content. These teachers read the 2017 curriculum document through their epistemic filter, viewing physics knowledge as mathematically oriented; this claim is evidenced by no teacher placed at the extreme end of believing that physics content was mathematically oriented reported concerns that the content in the 2017 curriculum document was too conceptual—they did not read this content as conceptual. In this study, more teachers communicating the belief that physics knowledge was conceptual were concerned about ensuring they fully understood the new (more conceptual) content in the 2017 curriculum document before teaching it. Those teachers focused on the mathematical content of physics knowledge might not have communicated this concern because they may not perceive the need for a nuanced understanding of the theory, provided their mathematics was well understood.

Finally, the extremity of teachers' epistemic beliefs about the content of physics knowledge showed connection to some of their concerns about the content in the 2017 Physics 30 curriculum document. Those teachers placed nearer either extreme on the continuum of epistemic beliefs about the content of physics knowledge were concerned about the amount of content in this curriculum document whereas those with less extreme beliefs tended not to communicate this concern. This concern was interpreted to be connected to a teacher's interpretation of outcomes and indicators along with implied content (see *5.2.1. Concerns about Increased Interpretation)*. Teachers interpreting this document as focused on teaching qualitative physics were not concerned about the conceptual physics in the document but, instead, the amount of review students needed to understand the necessary mathematics. On the other hand, mathematics-based teachers reported that they could not teach all the content in this curriculum because they interpreted the indicators and outcomes to include more mathematics than was explicitly included in the 2017 document. Teachers' views about the role of mathematics in physics have not been well researched (Mulhall & Gunstone, 2008), as epistemic research tends to focus on science teachers (as opposed to physics-specific investigations). Given this concern about content coverage and the lack of research into physics teachers' beliefs about mathematics in physics, I propose further investigation into teachers' views of the role of mathematics and how this influences their interpretation of a curriculum document.

5.3.2. Connecting Teachers' Epistemic Beliefs about Physics Knowledge with Management Concerns: Support and Resources

Teachers' epistemic beliefs about the content of physics knowledge were interpreted to be connected to concerns regarding the support of teachers and lack of resources. Concerns about a lack of resources and direction differed for teachers believing that physics knowledge was mathematically oriented and those believing that physics knowledge was conceptual and qualitative. Non-accredited teachers believing that physics knowledge was conceptual were concerned about their ability to prepare students for the Physics 30 provincial exam. Studies have shown teachers with low content knowledge (Borgerding et al., 2013; Gabby et al., 2017), heavy workloads (Kwok, 2014; Leung, 2008), and fewer professional development opportunities (Oguoma et al., 2019) typically focus on concerns about personal inadequacy and management of new curricula. This study furthers the work of previous researchers by contributing the finding that teachers' epistemic beliefs about the content of physics knowledge contributed to the types of management concerns they expressed.

Research has described the issue of disconnection between curriculum and standardized assessments (e.g., Abadie & Bista, 2018; Gabby et al., 2017; Ryder et al., 2014; Stadermann et al., 2019). Teachers in this study also reported concerns about a disconnect between the 2017 curriculum document and provincial examinations. The only three teachers to express concerns about their effectiveness in ensuring students' success on the provincial exam were not accredited and believed that physics knowledge was conceptual and qualitative. The other three non-accredited teachers were not concerned about preparing students for the provincial exam and believed that the content of physics knowledge stemmed from mathematics. Teachers that were concerned about provincial exam preparation discussed the exam's focus on 'equations' and mathematics-based content.

If a teacher sees physics as conceptual and reads the curriculum with this epistemic filter, when they encountered a mathematics-focused provincial exam (as described by these teachers) they questioned their capability to prepare students for these exams (at least that is what this data suggested). Stadermann and colleagues (2019) attribute a disconnect between curriculum and standardized exams to the difficulty of assessing some aspects of science (i.e., the qualitative and philosophical) with standardized exams. Due to this difficulty, the assessment focuses on different content than is focused on in the curriculum document (Stadermann et al., 2019). Curricula and standardized assessments (if they must be used) must be aligned, as discussed earlier in this chapter, but it may also be necessary to explicitly orient teachers to the epistemic assumptions informing standardized assessments so they can offer their students an epistemically-informed education.

Teachers' epistemic beliefs about the content of physics knowledge were connected to the types of resources they desired to assist their implementation of the 2017 curriculum document. Teachers communicating the belief that the content of physics knowledge was conceptual wanted classroom-ready strategies for implementing the content in the 2017 Physics 30 curriculum document and direction on what would be asked on the provincial exam (non-accredited teachers only). Teachers communicating the belief that physics knowledge was mathematically oriented wanted resources to teach the more abstract topics (i.e., fields and modern physics). Mathematics-oriented teachers also wanted more direction on how much class time to spend on each topic; they felt that this would help them decide how 'deep' to go into each topic. Given this finding, I concur with those studies (Borgerding et al., 2013; Gabby et al., 2017) suggesting the development of resources for teachers based on their specific needs.

Those overseeing new initiatives should use teachers' concerns, context, and beliefs to guide professional development offerings during the implementation process (Fischer et al., 2019; Gabby et al., 2017). I suggest to those implementing new physics curriculum documents to make differentiated resources and professional development opportunities[23] available for teachers based on their epistemic beliefs about the content of physics knowledge. For participants in this study, resources could have included classroom ready strategies and guidance on the provincial exam for the conceptual-physics teachers as well as explanation on the abstract topics and indications of expected time on each outcome for the mathematically oriented teachers.

5.4. Considering the Accreditation of Saskatchewan Physics Teachers

One recurring finding that was not part of my intended research questions was that non-accredited teachers tended to communicate similar concerns. The 2017 Saskatchewan Physics 30 curriculum had an open format with suggested indicators, allowing teachers more freedom in designing their courses. Unfortunately, with this increased professional trust in accredited teachers, non-accredited teachers were left trying to reconcile an epistemically differing curriculum and the provincial exam. All non-accredited teachers—even those who were not worried about their capabilities to prepare their students for the provincial exam—were

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[23] Studies such as Fischer et al. (2019) have found that teachers do not always choose professional development based on their types of concern, but I posit (based on personal experience) that this may differ in a context where opportunities are physics-specific and teachers' expressed concerns and communicated beliefs are used to guide the creation of targeted development opportunities.

concerned about a lack of resources and instructions to support the implementation of this curriculum document; two accredited teachers also reported this concern.

Accredited teachers in Saskatchewan had the “luxury” (as Harley put it) of developing a Physics 30 course that reflected how they saw physics. The Saskatchewan Ministry of Education encouraged teachers to exercise their autonomy and choose which indicators would meet each outcome, creating indicators if they saw the need. Alas, this autonomy was not a benefit for all teachers. Franz claimed the open layout of the 2017 curriculum document was “useless” to him because, as a non-accredited teacher, he had to ‘cover’ all of the indicators anyway to prepare his students for the provincial exam. Non-accredited teachers did not benefit from the open-format of the 2017 curriculum document. Unfortunately, non-accredited teachers felt forced into treating the indicators as a checklist to be met. The 2017 curriculum document offered more freedom to those teachers who could be trusted to assess Physics 30, that is, those teachers who did not have to prepare students to write a provincial exam.

Having non-physics trained physics teachers is a necessity in much of North America, including Saskatchewan. A shortage of high school physics teachers has led to teachers with little-to-no physics training taking over physics classrooms (Ogodo, 2019; Sheppard et al., 2020; Sunal et al., 2015; Sunal et al., 2019b). Sheppard et al. (2020) found that students of those physics teachers who were not physics specialists were outperformed by students of physics specialists in physics courses. Ogodo (2019) found that teachers who participated in professional development aimed at improving their physics understanding grew in their physics content knowledge. As discussed in *4.2.4.1. How are Others Teaching this Curriculum?* there were very few professional development opportunities offered specifically for Saskatchewan physics teachers. Perhaps, instead of having two different types of teachers of Physics 30 (accredited and non-accredited), it would be prudent to offer subject-specific training to improve teachers' physics pedagogical content knowledge. This might allow those non-accredited teachers to benefit from the outcome-indicator format of the 2017 Physics 30 curriculum document since they would not be bound to preparing students for a provincial exam.

Potentially, preparing out-of-field physics teachers in physics could remove the need for a provincial exam. As I understand it, the provincial exam is required by the Ministry of Education to ensure that students who have taken their physics course from a non-accredited teacher have learned 'enough' physics to pass Physics 30. Rimfield et al. (2019) found that U.K. teachers' assessments of learning were as reliable and valid as standardized test scores in high school. Assuming this result can translate to the Saskatchewan context, and in addition to training in physics content (as suggested by Ogodo, 2019), the Saskatchewan Ministry of Education might consider training and supporting their non-accredited teachers to reliably and validly assess their physics students instead of subjecting these students to provincial exams. This training and support could also satisfy the concerns regarding a lack of resources and instruction expressed by all non-accredited physics teachers in this study. Finally, through professional development aimed at learning the content, philosophy, and nature of physics, giving all teachers and—by proxy—their students a chance to benefit from the 'open' 2017 Saskatchewan Physics 30 curriculum document.

5.5. Discussion Conclusion

5.5.1. Conclusions About the Epistemic Beliefs About Physics Communicated by Saskatchewan Physics 30 Teachers

This study found that high school physics teachers' epistemic beliefs about physics knowledge did not always align with those epistemic beliefs common to experts (i.e., physicists and scholars of the philosophy and nature of physics). Previous studies have assumed that teachers' beliefs reflect those of expert scientists (e.g., Halloun, 1997; Halloun & Hestenes, 1998; Moore, 2018). According to my findings, teachers' epistemic beliefs about the certainty and structure of physics typically aligned with those of expert physicists. Similar to other studies (Burbules & Linn, 1991; Tsai, 2006; Sin, 2014), teachers in this study believed that physics knowledge could change but communicated that it was unlikely that the fundamentals of physics would change. Reflecting findings of previous studies (Kang & Wallace, 2005; Maggioni & Parkinson, 2008), teachers in this study described the certainty and structure of 'school' physics—which consisted of isolated and unlikely to change concepts—as differing from the structure of the discipline of physics—which was coherent and likely to change. Saskatchewan teachers' epistemic beliefs about the content of physics knowledge were similar to those of high school and early undergraduate students in previous studies (e.g., Hammer, 1994; Turşucu et al., 2017; Pospiech et al., 2019), showing that teachers also describe physics as conceptual and qualitative or mathematics-based and equation-focused. Finally, many teachers (13 of 16) conflated physics knowledge with the empirical evidence from which physics knowledge is created, contradicting both the epistemic beliefs expressed within the 2017 Saskatchewan Physics 30 curriculum document and the expert belief that physics knowledge was invented by humans. Having over 80% of teachers in this study express the epistemic belief that physics knowledge was discovered from an external reality supports Galili's (2018) claim that teachers often possess the content, pedagogical, and learning knowledge necessary to teach science but may need to spend more time exploring the philosophical underpinnings of science.

If this sample were representative of Physics 30 teachers in Saskatchewan, given the widely reported epistemic beliefs that physics was discovered, that fundamentals in physics are unlikely to change, that school physics and the discipline of physics are two different things, and the plurality of views on the role of mathematics in physics, in addition to revising the requirements for accreditation to teach physics in Saskatchewan (see *5.1.2. Beliefs about the Source of Physics*), I suggest that a professional learning community for Saskatchewan physics teachers be established.

A professional learning community specific to Saskatchewan physics teachers would offer an opportunity for physics teachers to discuss the content and philosophy of physics and physics education. A community might also alleviate teachers' concerns regarding isolation and a lack of peers with which to discuss the 2017 curriculum document (and physics teaching in general). As Sunal et al. (2019b) suggest, a virtual meeting space would be ideal for use with physics teachers since they are often alone as subject specialists within a school. Unlike Sunal et al. (2019a), I would not suggest solely focusing on discussing the concepts taught in grade 12 physics but also direct conversations towards having teachers explore their own epistemic beliefs about physics knowledge and how this impacts their interpretation of curriculum. Of course, having a focus on the philosophy of and epistemic beliefs about physics should not be devoid of content; content knowledge is vital to the success of any physics teacher and should be included in their professional development (Sunal et al., 2019a; Sunal et al., 2019b). A community of physics teachers could be developed through multiple contact points including discussions about how they are teaching, what they are teaching (content), knowing in physics, epistemic beliefs, the front matter of the curriculum document, philosophies of physics, and the nature of physics among other topics.

5.5.2. Conclusions about the Concerns About the 2017 Saskatchewan Physics 30 Curriculum Document Expressed by Teachers in this Study

In reviewing the literature (see *2.3.2. Research about Teacher Concerns and New Science Curricula*), I identified three areas of concern expressed by teachers' when undergoing science curriculum changes, which were concerns about (a) content changes, (b) uncertainty with content and direction, and (c) lack of coherence between curricula and assessments. Contributing to the literature from a Western Canadian context, each of these identified concerns was reflected by teachers in this study with the addition of concerns about isolation. Concerns about physics teacher isolation were not represented in the teacher concerns literature but have been identified by other researchers working with physics teachers (e.g., Kelly & Sheppard, 2010; Nehmeh & Kelly, 2018; Tesfaye & White, 2012).

Literature-identified concerns were reflected in Saskatchewan teachers' concerns regarding to the variance in Physics 30 courses created by (a) the structure of the 2017 curriculum document and (b) a lack of resources accompanying the 2017 curriculum document and instruction/direction on what should be emphasized from this document. Teachers wanted more direction about how this content should be taught, including the interpretation of some indicators. This interpretation was requested because, depending on how teachers read the document, several indicators and outcomes could balloon into full semester courses. Additionally, non-accredited teachers reported being unsure about what indicators would be emphasized on the provincial exam. Teachers wanted to know the depth and breadth of the content to cover and they wanted assistance in ensuring the 2017 curriculum document was interpreted 'correctly.'

To me, these concerns about variance in Physics 30 courses were a symptom of a miscommunication on the part of those implementing this curriculum document regarding the purpose of the curriculum document. It would appear many teachers read this document as a checklist—or at least they wanted to—and this might be because the 1992 document read like a checklist. This 'checklist' view of curriculum was even more evident for those having to prepare their students for a provincial exam. However, the 2017 curriculum document indicated that students were only required to achieve the overarching outcomes; the indicators were suggestions to meet these outcomes. It would appear this document was not intended to be a number of checkpoints students must reach in sequence but, rather, a guide of the main areas to which they should be exposed. If this was indeed the intention of those mandating the 2017 curriculum document, I suggest that the Saskatchewan Ministry of Education develop resources aimed at clarifying their positions on the purpose of curriculum documents, their motivations behind and the research informing the design of the Saskatchewan science curricula, and instructional resources to assist teachers in their classroom planning.

5.5.3. Conclusions about Connections Between Teachers' Epistemic Beliefs About Physics Knowledge and their Concerns Regarding the 2017 Saskatchewan Physics 30 Curriculum Document

Differences in epistemic beliefs about the source and the content of physics knowledge were connected to some concerns raised during this study. Given the existence of connections between epistemic beliefs about physics knowledge and concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, this study highlighted the importance of investigating teachers' reactions to epistemic (in)congruence with documents/resources. Recent research has explored epistemic congruence with students (Pekrun et al., 2017; Muis et al., 2015;

Muis et al., 2018; Rosman & Mayer, 2018), but epistemic congruence has yet to be thoroughly explored with teachers. Considering concerns as an epistemic emotion, this study indicates that this area may be of interest for future educational researchers and teacher educators.

Findings from this study offer several areas requiring further consideration. Epistemic beliefs literature has heavily focused on students (e.g., Adams et al., 2006; Buehl & Alexander, 2005; Domert et al., 2007; Muis et al., 2018; Pekrun et al., 2017; Rosman & Mayer, 2018; Schommer, 1990; Yavuz, 2014) and (more recently) pre-service or beginning teachers (e.g., Larkin et al., 2019; Lohse-Bossenz, 2019; Merk et al., 2017; Wei & Chen, 2019). Extending these studies, this research highlighted (a) a need to further explore the epistemic beliefs of experienced, practicing physics teachers as these beliefs may not always align with physicists and scholars of the philosophy of physics (as was previously assumed). Additionally, this study highlighted (b) the importance of hearing teachers' voices as related to curriculum change. In response to these voices, I have presented several recommendations for those implementing new curriculum documents. Finally, given the connections between teachers' epistemic beliefs about physics knowledge and their concerns regarding the 2017 Saskatchewan Physics 30 curriculum document, (c) findings suggest that those implementing curriculum documents create documents that are readable and interpretable for teachers of varying epistemic beliefs. Educational change is inevitable (Fullan, 2016); it is important that teachers are supported, heard, and epistemically informed throughout these changes.

CHAPTER 6: REFLECTIONS

In the fall of 2014, I embarked on my doctoral journey. I knew this pursuit would be transformative but looking back it is difficult to recall how I expected to change. Of course, I have a much deeper understanding and appreciation of the constructed knowledge systems describing epistemic beliefs about physics knowledge and teacher concerns, but this quest has been about more. I have grown as a researcher through failures, perseverance, justifying my positions, and questioning. In posing and pursuing my research questions, I developed my "power to perceive critically the way [I] exist in the world with which and in which [I] find [myself]," (Friere, 1972, p. 83). I cannot return to the (admittedly more naïve) ways from which I saw research and education but I can offer useful questions intended to promote alternative approaches to viewing aspects of our shared human reality.

In this brief chapter, I reflect on some of these changes through significant incidents during my research including validating my survey, unexpected accusations, and my difficulties in accessing participant teachers.

6.1. The Trouble with Validation

As mentioned in *3.2. Historical contexts of research,* it was common for studies of both epistemic beliefs and teachers' concerns to use quantitative research (i.e., surveys). In most studies, Cronbach's alpha was included as an indication of the reliability of the scales within a survey (often given only in a single sentence in the manuscript) and no specific measure for validity was reported. Seeing these measures, and using the work of DeVellis (2012), I concluded that survey development required verifying the reliability and validity of any quantitative instrument. Based on these articles (e.g., Buehl &Alexander, 2005; Duffy et al., 2017; Muis et al., 2019; Schommer, 1990) and DeVellis' text, validating a survey seemed to be a straightforward process. It was not!

As no existing instrument had been located in the literature, I attempted to develop and validate a new survey to measure teachers' epistemic beliefs about physics knowledge (see Appendix F). A three-factor solution was produced through exploratory factor analysis (see Appendix G) with significant changes to the original 29-item instrument to achieve this solution, hence, along with other confounding factors, I questioned the acceptability of this solution. I recognize that further factor analyses, including exploratory and confirmatory factor analysis methods, conducted with different samples of science teachers might serve to establish the validity and reliability of this survey. Acceptable solutions could also be found with item-analysis or other approaches; as I was learning this skill using the epistemic beliefs literature, I conducted factor analysis as had been done in previous studies (see Adams et al., 2006; Schommer 1990, 1994a; Hofer, 2000; Wheeler, 2007). Yet, as I have written in Watson (2020) and further explained below, I question whether factor analysis truly shows the validity of a survey investigating beliefs.

Despite the simplicity with which previous surveys appeared to be deemed reliable, I neglected to consider that beliefs are all loosely connected (especially in epistemic beliefs research, as discussed by Schommer (1990, 1994a) and Hofer (2000)). This implied that separating factors in any analysis might be difficult to achieve (and justify). As indicated by Elby (2011), traditional methods of survey validation can be difficult in beliefs research since they lack the subtle approach necessary for this area of research. It has also been recently noted that Likert scale surveys rarely measure epistemic beliefs adequately (Adibelli & Bailey, 2017). Notwithstanding these significant problems, it was still common in the literature for researchers to use quantitative instruments in epistemic belief research in education. As described in Appendix F, I found it quite difficult to validate and verify the reliability of this survey. Ultimately, I concluded that my survey results should not be used as they were too convoluted.

In this study, teachers' epistemic belief profiles were therefore determined through interviews and member-checking with participants. Admittedly, qualitative data collection, such as interviewing, forces researchers to use a smaller sample size than would be achievable with surveys, but I was certainly more confident in my epistemic belief profiles determined through interviews than those that were measured from surveys. Perhaps, given the messy and layered nature of beliefs (Pajares, 1992), an approach where the nuances associated with beliefs research can be unpacked and explored, such as qualitative research, is needed when investigating constructs such as beliefs and concerns?

6.2 The Ethical Teacher

When trying to recruit participants, I was told that it was 'unethical' for me to question the government-mandated curriculum documents, especially as a writer of one of these documents. I found this accusation both troubling and curious; troubling because I did not see my questions as unethical but as having the potential to improve teachers' interactions with the Saskatchewan Physics 30 curriculum document and curious because I was most certainly operating with a different idea of the 'ethical teacher' from the person who told me this.

I see an ethical teacher as an engaged citizen; a person who "question[s], critically examine[s], advocate[s], and defend[s] rights and responsibilities," (Concentus et al., 2019, n.p.). Ethical teachers should be encouraged to question the system in which they operate (Watson & Rose, 2019). The teacher is not "a cog in a wheel, expected merely to respond and transmit external energy," in fact, it is "advisable that the teacher should understand, and even be able to criticize the general principles upon which the whole education system is formed and administered," (Dewey, 1895 as cited in Goldstein, 2014, p.1). The ethical teacher, in my reality, has a duty to question.

Literature has discussed the ethical teacher in terms of their relationships with students and guardians (Campbell, 2003), but discussions regarding the ethics of teachers in relation to questioning those power structures (i.e., school systems) in which they are employed have faded from the educational research discussion. I suggest educational researchers investigate avenues such as the parallel between school systems and Foucault's (1995) panopticon, defining the ethical teacher in relation to hidden (and visible) power structures in education, and the illusion of teacher ownership. Additionally, I would be curious to explore how classroom teachers define the 'ethical teacher' when it comes to interaction with the school division and government-mandated initiatives and then considering how these definitions differ from those definitions of educational researchers? Perhaps this could show some structures fueling what is often perceived as the 'practice-theory gap'.

6.3. Realities of Accessing Teachers

As discussed in Appendix F*,* some Saskatchewan school divisions were keen to offer teachers in their employ the opportunity to engage with this study, some ignored my requests, and others would not permit me to work with 'their' teachers. As a result, throughout my research, I wrestled with a larger question; why deny educational researchers access to teachers?

School divisions rejected my request to pass on an email to 'their' physics teachers inviting them to participate in this research. I struggle with the term 'our teachers' used by many school divisions. Teachers are educated adults, able to make their own decisions about those projects in which they want to engage and this may include participating in research, even if the research is forwarded by the school division. For example, a participant who volunteered to be interviewed (through collegial connections) worked for a school division that rejected my request to conduct research with their teachers. I informed the teacher of this and asked whether they wanted to proceed; they did. After the interview, this teacher expressed appreciation for the opportunity to engage with this research. If I had not reached out to this teacher's colleague, they would not have had this opportunity since their school division had rejected the request. I understand the need to protect students within a school division; parents trust the school to make decisions with the welfare of their child in mind. Yet, teachers are not students. As teachers are educated and consenting adults, I believe that they should be offered the choice of whether or not they wish to participate in educational research.

The unanticipated rejections for my research were frustrating (to say the least) but also revealed interesting seams of research. School system policies as potential barriers to teacher agency are understudied (Pantic, 2015), yet, in talking to my fellow researchers, many of us have stories about roadblocks and similar experiences in trying to research with teachers. This study was not out to ask (or answer) these questions about power structures, but it was certainly an unexpected, and interesting, finding for me.

3.3. Final Thoughts

In *becoming*[24] a researcher I have transitioned from my former state of being to a state where I am better equipped to analyze aspects of my reality. In crafting, pursuing, and answering my research questions, I have contributed to the field of educational research with the intent of

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[24] The word *becoming* refers to the process of transitioning from what Heidegger called the state of *being* into a desired state (of *becoming*) through transformative moments in one's learning journey (Natanasabapathy & Maathuis-Smith, 2019).

promoting support for teachers (which has been declining as of late) and teacher voice. I intend to disseminate these findings to the academic community through future publications and conference talks. I plan to bring these findings to the attention of teachers, since—in the (paraphrased) words of my supervisor, Dr. Gregory Thomas—educational research should always aim to help teachers or students in some way. I aim to help teachers share their voice and explore their beliefs.

I have experienced and overcome failure (i.e., my survey); failure that I am going to experience again at some point in my academic career as this is likely not the last survey I will create nor the last survey I fail to validate. Still, I have learned more about statistical analysis and a new way of looking at data, analysis, and data collection. Additionally, this experience of survey validation has taught me the value and power of the professional judgement of the researcher. I was able to determine whether items were conceptually consistent, moving beyond relying on numerical results and toward making decisions based on my expertise.

Educational decisions are commonly made without consulting teachers (Dunn et al., 2017). As a classroom teacher, I knew the reality of this claim, but I am unsure whether I recognized all that was decided for me before undertaking this study. If I had the opportunity to participate in research such as this study as a teacher, I would have been more than happy to offer my voice. However, many school divisions prevented this opportunity from even reaching their teachers. I believe that these divisions felt they were acting in the best interest of 'their' teachers, even if these rejections prevented teachers from even having the opportunity to engage in discipline-specific research that allowed them to share their voices regarding a new curriculum document. Through this experience, I have gained perspective (and formulated questions) regarding the role of teachers in a school division and the meaning of an ethical teacher when considering educational research.

In growing my expertise on these topics, I recognize limitations of my knowledge. My thinking has changed immensely since the commencement of this program. One could say that my personal epistemology of the world has progressed toward evaluative thinking (Hofer, 2012; Hofer & Pintrich, 1997; Perry, 1970), where knowledge is socially constructed through assertions which are evaluated based on criteria, argument, and evidence. Before this experience, I recognized the relative nature of knowing but still held some absolutist tendencies, believing in facts that described a directly knowable reality. I may be more of an expert in the fields of epistemic beliefs about physics knowledge and teacher concerns, able to judge and evaluate new information, but I am certainly not an expert in many things and have much to learn.

Moving from teacher to teacher-researcher and, now, to educational researcher has been a journey filled with frustration, stretching, and growth. *Becoming* through failure and encountering unexpected roadblocks have opened my gaze to other academic pursuits within education beyond science education. Despite moving from a classroom teacher to an educator of future teachers during this journey and, now, adding educational researcher to that list, I predict that I will always see myself as a physics/mathematics/science teacher and aim to continue supporting my colleagues with my future pursuits.

REFERENCES

Abadie, M. & Bista, K. (2018). Understanding the stages of concerns: Implementation of the common core state standards in Louisiana schools. *Journal of School Administration Research and Development, 3*(1), 57 – 66. https://www.ojed.org/index.php/JSARD/issue/view/105

Abtahi, Y., & Barwell, R. (2019). Mathematical morality tales: Mathematics education in Canadian newspapers. *Canadian Journal of Science, Mathematics and Technology Education. 19*(1), 48 – 60. https://doi.org/10.1007/s42330-019-00042-0

Abd-El-Khalick, F., Myers, J., Summers, R., Brunner, J., Waight, N., Wahbeh, N., Zeineddin, A. A., Belarmino, J. (2017). A longitudinal analysis of the extent and manner of representations of nature of science in U.S. high school biology and physics textbooks. *Journal of Research in Science Teaching, 54*(1), 82 – 120. https://doi.org/10.1002/tea.21339

Adams, W. K., Perkins, K. K., Podolefsky, N.S., Dubson, M., Finkelstein, N.D., & Weiman, C.E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado learning attitudes about science survey. *Physical Review Special Topics – Physics Education Research, 2*(1), 1 – 14. https://doi.org/10.1103/PhysRevSTPER.2.010101

Adibelli, E., & Bailey, J. (2017). Exploring the factors contributing to preservice elementary teachers' epistemological worldviews about teaching science. In G. Schraw, J. Lunn Brownlee, L. Olafson, & M. VanderVeldt (Eds.), *Teachers' personal epistemologies: Evolving models for transforming practice* (pp. 291 - 322). Information Age Press.

Alexander, P.A., & Dochy, F. J. R. C. (1995). Conceptions of knowledge and beliefs: A comparison across varying cultural and educational communities. *American Educational Research Journal, 32*(2), 413 – 442. https://doi.org/10.3102%2F00028312032002413

Anderson, R. K. (2017). *Student development as cross-disciplinary team members: Real-time observations of student experiences during a team project* (Publication No. 1875) [Doctoral dissertation, Clemson University]. *All Dissertations*. https://tigerprints.clemson.edu/all_dissertations/1875

Anderson, R. K. & Martin, J. P. (2017, June). *A real report from the trenches of a Ph.D. dissertation: Exploring the inherent "messiness" of engineering education research through an audit trail* [Paper presentation]. 2017 American Society for Engineering Education, Columbus, OH, U.S.A. https://peer.asee.org/27504

Anderson, S. (1997). Understanding teacher change: Revisiting the concerns based adoption model. *Curriculum Inquiry, 27*(3), 331 – 367. https://doi.org/10.1111/0362-6784.00057

Aoki, T. T. (2005). *Curriculum in a new key: The collected works of Ted T. Aoki*. W. Pinar & R. L. Irwin (Eds.). Lawrence Erlbaum Associates, Publishers. https://doi.org/10.4324/9781410611390

Ashraf, T. (2019). Experiences and impact: The voices of teachers on math education reform in Ontario, Canada. In Bulgarian Comparative Education Society (Eds.) *Global education in practice: Teaching, researching, and citizenship, Vol. 17* (pp. 101 – 107). Bulgarian Comparative Education Society. https://eric.ed.gov/?id=ED596920

Bailey, D., Jr. & Palsha, S. (1992). Qualities of the stages of concern questionnaire and implications for educational innovations. *The Journal of Educational Research, 85*(4), 226 – 232. https://www.jstor.org/stable/27540479

Barbera, J., Adams, W. K., Wieman, C. E., & Perkins, K. K. (2008). Modifying and validating the Colorado learning attitudes about science survey for use in chemistry. *Journal of Chemical Education, 85*(10), 1435 – 1439. https://doi.org/10.1021/ed085p1435

Barnes, B., Bloor, D., & Henry, J. (1996). *Scientific knowledge: A sociological analysis*. University of Chicago Press.

Baytelman, A., Iordanou, K., & Constantinou, C. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching,* 57(8), 1199-1227. https://doi.org/10.1002/tea.21627

Bazeley, P. (2013). *Qualitative data analysis: Practical strategies.* SAGE.

Bazeley, P. (2018a). *Integrating analyses in mixed methods research*. SAGE. https://dx.doi.org/10.4135/9781526417190

Bazeley, P. (2018b). "Mixed methods in my bones": Transcending the qualitative-quantitative divide. *International Journal of Multiple Research Approaches, 10*(1), 334 – 341. https://doi.org/10.29034/ijmra.v10n1a22

Belenky, M., Clinchy, B., Goldberger, N. & Tarule, J. (1986). *Women's ways of knowing: The development of self, voice and mind*. Basic Books.

Belief. (2016) In *OED Online*. Oxford University Press. Retrieved May 3, 2016 online at http://www.oed.com.login.ezproxy.library.ualberta.ca/view/Entry/17368?redirectedFrom=belief#eid

Bendixen, L. (2012). A process model of epistemic belief change. In B. Hofer & P. Pintrich (Eds.) *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 191 – 208). Routledge.

Berends, M. (2006). Survey methods in educational research. In J. Green, G. Camilli & P. Elmore (Eds.) *Handbook of complementary methods in education research* (pp. 623–640). American Educational Research Association. https://doi.org/10.4324/9780203874769

Bigozzi, L., Tarchi, C., Fiorentini, C., Falsini, P., & Stefanelli, F. (2018). The influence of teaching approach on students' conceptual learning in physics. *Frontiers in Psychology, 9*(2474), 1 – 14. https://doi.org/10.3389/fpsyg.2018.02474

Blaikie, N. (2010). *Designing social research* (2nd Ed.). Polity Press.

Brodsky, A. (2008). Negative case analysis. In L. M. Given (Ed.), *The SAGE encyclopedia of qualitative research methods* (pp. 552-553). SAGE Publications Ltd. https://dx.doi.org/10.4135/9781412963909

Borgerding, L., Sadler, T., & Koroly, M. (2013). Teachers' concerns about biotechnology education. *Journal of Science Education & Technology, 22*(2), 133 – 147. https://doi.org/10.1007/s10956-012-9382-z

Boz, N., & Boz, Y. (2014). Are pre-service mathematics teachers' teaching concerns related to their epistemological beliefs? *Croatian Journal of Education, 16*(2), 335 – 362. https://cje2.ufzg.hr/ojs/index.php/CJOE/issue/view/25/showToc

Brahmia, S. M. (2014). *Mathematization in introductory physics*. (Doctoral thesis). Rutgers University Graduate School, New Brunswick. https://doi.org/doi:10.7282/T3FB51D8

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brenner, M. (2006). Interviewing in educational research. In J. Green, G. Camilli & P. Elmore (Eds.) *Handbook of complementary methods in education research* (pp. 357 – 370). American Educational Research Association. https://doi.org/10.4324/9780203874769

Brinkmann, S., & Kvale, S. (2015). *InterViews: Learning the craft of qualitative research reviewing* (3rd edition). Sage Publishing.

Buehl, M. M., & Alexander, P. A. (2005). Motivation and performance differences in students' domain-specific epistemological belief profiles. *American Educational Research Journal*, *42*(4), 697 – 726. https://doi.org/10.3102/00028312042004697

Brownlee, J., & Schraw, G. (2017). Reflection and reflexivity: A focus on higher order thinking in teachers' personal epistemologies. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 409 - 427). Information Age Publishing, INC.

Buehl, M., & Fives, H. (2016). The role of epistemic cognition in teacher learning and practice. In I. Braten, W. Sandoval & J. Greene (Eds.) *Handbook of epistemic cognition* (pp. 206 – 220). Routledge. https://doi.org/10.4324/9781315795225

Burbules, N. & Linn, M. (1991). Science education and philosophy of science: Congruence or contradiction? *International Journal of Science Education*, *13*(3), 227 – 241. https://doi.org/10.1080/0950069910130302

Campbell, E. (Ed.) (2003). *The ethical teacher.* Open University Press.

Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, and Social Sciences and Humanities Research Council of Canada (2015). *Tri-Council policy statement: Ethical conduct for research involving humans.* https://ethics.gc.ca/eng/policy-politique_tcps2-eptc2_2018.html

Carpenter, S. (2018). Ten steps in scale development and reporting: A guide for researchers. *Communication Methods and Measures, 12*(1), 25-44. https://doi.org/10.1080/19312458.2017.1396583

Carter, B. (1974). Large number of coincidences and the anthropic principle in cosmology. In M.S. Longair (Ed.), *Confrontation of cosmological theories with observational data: Proceedings of the symposium, Krakow, Poland, September 10 – 12, 1973* (pp. 291 – 298). D. Reidel Publishing Co. http://adsabs.harvard.edu/full/1974IAUS...63..291C

Charalambous, C., & Philoppou, G. (2010). Teachers' concerns and efficacy beliefs about implementing a mathematics curriculum reform: Integrating two lines of inquiry. *Educational Studies in Mathematics, 75*(1), 1 – 21. https://doi.org/10.1007/s10649-010-9238-5

Chaudhry, S. (2019). Mending mathematics : Will STEM education be our salvation? *Canadian Teacher, 15*(2), 8 – 9. https://canadianteachermagazine.com/2019/01/19/mending-mathematics-will-stem-education-be-our-salvation/

Chernoff, E. (2019). The Canadian math wars. *Canadian Journal of Science, Mathematics and Technology Education. 19*(1), 73 – 76. https://doi.org/10.1007/s42330-018-0037-9

Cheung, D., Hattie, J., & Ng, D. (2001). Reexamining the stages of concern questionnaire: A test of alternative methods. *The Journal of Educational Research, 94*(4), 226 – 236. https://doi.org/10.1080/00220670109598756

Chevrier, M., Muis, K., Trevors, G., Pekrun, R., & Sinatra, G. (2018). Exploring the antecedents and consequences of epistemic emotions. *Learning and Instruction, 63*, 1 – 18. https://doi.org/10.1016/j.learninstruc.2019.05.006

Chinn, C., & Barzilai, Z. (2017, April). *Rethinking the goals of epistemic education* [Paper Presentation]. The Annual Meeting of the American Educational Research Association, San Antonio, TX.

Christou, C., Eliophotou-Menon, M., & Philippou, G. (2004). Teachers' concerns regarding the adoption of a new mathematics curriculum: An application of CBAM. *Educational Studies in Mathematics, 57*(2), 157 – 176. https://doi.org/10.1023/B:EDUC.0000049271.01649.dd

Cohen, L. & Manion, L. (1994). *Research Methods in Education* (4th Edition). Croom Helm Ltd.

Concentus, Saskatchewan Human Rights Commission, Law Foundation of Saskatchewan, & Government of Saskatchewan. (2019). *Curriculum outcomes [Webpage]*. Retrieved on November 4, 2019 from https://www.concentus.ca/curriculum-outcomes/

Continuum. (2016) In *OED Online*. Oxford University Press. Retrieved May 11, 2016 online at http://www.oed.com.login.ezproxy.library.ualberta.ca/view/Entry/40283?redirectedFrom=continuum#eid

Council of Ministers of Education, Canada. (1993). *Victoria Declaration 1993*. Toronto, ON. http://www.cmec.ca/publications/lists/publications/attachments/251/victoria-declaration-1993.pdf

Council of Ministers of Education, Canada. (1997). *Common framework of science learning outcomes, K to 12: Pan-Canadian protocol for collaboration on school curriculum*. Toronto, ON. https://science.cmec.ca/

Creswell, J. (2009). *Research Design: Qualitative, quantitative, and mixed method approaches* (3rd ed.) Sage.

Creswell, J. W. (2015). *A concise introduction to mixed methods research.* Sage.

Creswell, J., W. & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed). SAGE

Daniel, L. & Onwuegbuzie, J. (2002, November). *Reliability and qualitative data: Are psychometric concepts relevant within an interpretivist research paradigm?* [Paper Presentation]. Annual Meeting of the Mid-South Educational Research Association, Chattanooga, TN. https://eric.ed.gov/?id=ED471306

Darling-Hammond, L., & Richardson, N. (2009). Teacher learning: What matters? *Educational Leadership, 66*(5), 46 – 53. http://www.ascd.org/publications/educational-leadership/feb09/vol66/num05/toc.aspx

Davis, B. (2004). *Inventions of teaching: A genealogy.* Laurence Erlbaum Associates, Inc. https://doi.org/10.4324/9781410610096

Davis, E., Petish, D., Smithey, J. (2006). Challenges new teachers face. *Review of Educational Research, 76*(4), 607 – 651. https://doi.org/10.3102%2F00346543076004607

De Boer, G. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582 – 601. https://doi.org/10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

Deniz, H. (2017). Personal epistemology, nature of science and instructional practice: Towards defining a meaningful relationship. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) Teachers' *personal epistemologies: Evolving models for informing practice*, (pp. 169 – 190). Information Age Publishing, Inc.

Denzin, N. (2015). Triangulation. In G. Ritzer, J. M. Ryan, & B. Thorn. (Eds.) *The blackwell encyclopedia of sociology* (pp. 1 – 6). John Wiley & Sons. https://doi.org/10.1002/9781405165518.wbeost050.pub2

Desimone, L. (2011). A primer on effective professional development. *Phi Delta Kappan, 92*(6), 68 – 71. https://doi.org/10.1177%2F003172171109200616

Dewey, J. (1916). *Democracy and education: An introduction to the philosophy of education*. The Macmillan Company.

DeVellis, R. (2012). *Scale development: Theory and applications* (3rd ed.). SAGE.

Dolphin, G. R. & Tillotson, J. W. (2015). "Uncentering" teacher beliefs: The expressed epistemologies of secondary science teachers and how they relate to teacher practice. *International Journal of Environmental and Science Education, 10*(2), 21 – 38. http://www.ijese.net/makale/145.html

Domert, D., Airey, J., Linder, C., & Kung, R., L. (2007). An exploration of university physics students' epistemological mindsets towards the understanding of physics equations. *Nordic Studies in Science Education, 3*(1), 15 – 28. https://doi.org/10.5617/nordina.389

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5 – 12. https://doi.org/10.3102/0013189X023007005

Duffy, M., Muis, K., & Foy, M. (2017). Clearing a path for constructivist beliefs: Examining constructivist pedagogy and pre-service teachers' epistemic and learning beliefs. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 265 - 290). Information Age Publishing.

Dunn, A., Farver, S., Guenther, A. Wexler, L. (2017). Activism through attrition?: An exploration of viral resignation letters and the teachers who wrote them. *Teaching and Teacher Education, 64*, 280 – 290. https://doi.org/10.1016/j.tate.2017.02.016

Edwards, A., Brownlee, J., & Berthelsen, D. (2017). Self-authorship as a framework for understanding the professional identifies of early childhood practitioners. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 113-140). Information Age Publishing.

Eichenaub, M. & Redish, E. (2019). Blending physical knowledge with mathematical form in physics problem solving. In G. Pospiech, M. Michelini & B. Eylon (Eds.) *Mathematics in physics education* (pp. 127-151). Springer. https://doi.org/10.1007/978-3-030-04627-9

Eisner, E. W. (1997). The promise and perils of alternative forms of data representation. *Educational Researcher, 26*(6), 4-10. https://doi.org/10.3102%2F0013189X026006004

Elby, A. (2011). Getting started with research on epistemologies and expectations in getting started in PER. In C. Henderson & K.A. Harper (Eds.) *Reviews in PER, Vol 2*. (pp. 1 – 33). http://www.per-central.org/items/detail.cfm?ID=10578

Elby, A., Frederiksen, J., Schwarz, C., & White, B. (1997). *Epistemological beliefs assessment for physical science (EPABS).* Retrieved September 28, 2016 at http://www2.physics.umd.edu/~elby/EBAPS/home.htm

Elby, A., Macrander, C., & Hammer, D. (2016). Epistemic cognition in science. In J. Greene, W. Sandoval, & I. Braten (Eds.) *Handbook of epistemic cognition* (pp. 99 – 110). Taylor & Francis.

Enriquez, A. (2019). *Epistemological understanding as an organizing principle for inquiry and NOS in secondary science classrooms* [Paper presentation]. Annual Meeting of the American Educational Research Association, Toronto, ON.

Erduran, S. & Kaya, E. (2019). Epistemic beliefs and teacher education. In *Transforming teacher education through the epistemic core of chemistry: Empirical evidence and practical strategies* (pp. 5 - 80). Springer Nature. https://doi.org/10.1007/978-3-030-15326-7

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

Feucht, F. (2017). The epistemic climate of Mrs. M's science lesson about the woodlands as an ecosystem: A classroom-based research study. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 55 - 85). Information Age Publishing.

Fielding, N. (2012). Triangulation and mixed methods designs: Data integration with new research technologies. *Journal of Mixed Methods Research, 6*(2), 124-136. https://doi.org/10.1177%2F1558689812437101

Fischer, C., McCoy, A., Foster, B., Eisenkraft, A., & Lawrenz, F. (2019). Use of the stages of concern questionnaire in a national top-down reform effort. *Teaching and Teacher Education, 80*, 13 – 26. https://doi.org/10.1016/j.tate.2018.12.019

Fives, H. & Buehl, M. (2012). Spring cleaning for the "messy" construct of teachers' beliefs: What are they? Which have been examined? What can they tell us? In K. Harris, S. Graham & T. Urdan (Eds.) *APA educational psychology handbook, Vol 2: Individual differences and cultural and contextual factors* (pp. 471 – 499). American Psychological Association. https://doi.org/10.1037/13274-000

Fives, H., & Buehl, M. (2017). The functions of beliefs: Teachers' personal epistemology on the pinning block. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 25 - 54). Information Age Publishing, INC.

Foucault, M. (1995). *Discipline and punish: The birth of the prison.* Penguin Books.

Friere, P. (1972). *Pedagogy of the oppressed.* Penguin.

Fullan, M. (2016). *The new meaning of educational change* (5th ed.). Teachers College Press.

Fuller, F. (1969). Concerns of teachers: A developmental conceptualization. *American Educational Research Journal, 6*(2), 207-226. https://doi.org/10.3102%2F00028312006002207

Gabby, S., Avargil, S., Herscovitz, O. & Dori, Y. J. (2017). The case of middle and high school chemistry teachers implementing technology: Using the concerns-based adoption model to assess change processes. *Chemistry Education Research and Practice, 18,* 214-232. https://doi.org/10.1039/C6RP00193A

Galili, I. (2018). Scientific knowledge as a culture: A paradigm for meaningful teaching and learning of science. In M. Matthews (Ed.) *History, philosophy and science teaching: New perspectives* (pp. 203-233). Springer International Publishing. https://doi.org/10.1007/978-3-319-62616-1

Geng, J., Jong, M., & Chai, C. (2019). Hong Kong teachers' self-efficacy and concerns about STEM education. *Asia-Pacific Education Researcher, 28*(1), 35 – 45. https://doi.org/10.1007/s40299-018-0414-1

George, A., Hall, G., & Stiegelbauer, S. (2006). *Measuring implementation in schools: The stages of concern questionnaire.* Southwest Educational Development Laboratory. https://sedl.org/cbam/socq_manual_201410.pdf

Goddu, K. (2012). Meeting the challenge: Teaching strategies for adult learners. *Kappa Delta Pi Record, 48*, 169 – 173. https://doi.org/10.1080/00228958.2012.734004

Goldstein, D. (2014). *The teacher wars: A history of America's most embattled profession.* Doubleday.

Government of Canada (2016). *Census profile, 2016 census*. Retrieved Oct. 31, 2019 from https://www.statcan.gc.ca

Government of Saskatchewan (2019). *Teacher accreditation*. Retrieved January 5, 2019 from https://www.saskatchewan.ca/

Gregory, B. (1988). *Inventing reality: Physics as language*. John Wiley & Sons, Inc.

Grix, J. (2004). *The foundations of research*. Palgrave MacMillan.

Gu, Ji. (2016). *Epistemic beliefs of middle and high school students in a problem-based, scientific inquiry unit: An exploratory, mixed methods study.* [Unpublished thesis]. Utah State University. https://digitalcommons.usu.edu/etd/4674

Guba, E. (1990). The alternative paradigm dialog. In Guba, E. (Ed.) *The paradigm dialog* (pp. 17 – 30). Sage Publications, Inc.

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

Gudyanga, R., & Jita, L. (2018). Mapping physical sciences teachers' concerns regarding the new curriculum in South Africa. *Issues in Educational Research, 28*(2), 405 – 421. http://www.iier.org.au/iier28/gudyanga.pdf

Guskey, T. (2009). Closing the knowledge gap on effective professional development. *Educational Horizons, 87*(4), 224 – 233. https://eric.ed.gov/?id=EJ849021

Hall, G., & Hord, S. (2015). *Implementing change: Patterns, principles, and potholes* (4th edition). Pearson Education, Inc.

Hall, G. & Hord, S. (1987). *Change in schools: Facilitating the process*. State of New York Press.

Hall, G., George, A., & Rutherford, W. (1979). *Measuring the stages of concern about an innovation: A manual for use of the stages of concern questionnaire.* Austin: The University of Texas, Research and Development Center for Teacher Education, ERIC Document Reproduction Service No. ED147342. https://eric.ed.gov/?id=ED147342

Hall, G., Wallace, R., & Dossett, W. (1973). *A developmental conceptualization of the adoption process within education institutions* (Report No. 3006). Austin: The University of Texas at Austin, Research and Development Center for Teacher Education. https://eric.ed.gov/?id=ED095126

Halloun, I. (1997). Views about science and physics achievement: The VASS story. *American Institute of Physics Conference Proceedings, 399*(1). https://doi.org/10.1063/1.53156

Halloun, I. & Hestenes, D. (1998). Interpreting VASS dimensions and profiles for physics students. *Science & Education, 7*(6), 553 – 577. https://doi.org/10.1023/A:1008645410992

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction, 12*(2), 151 – 183. https://www.jstor.org/stable/3233679

Hansson, L., & Leden, L. (2016). Working with the nature of science in physics class: Turning 'ordinary' classroom situations into nature of science learning situations. *Physics Education, 51*, 1 – 6. https://iopscience.iop.org/article/10.1088/0031-9120/51/5/055001

Harris, L., & Brown, G. (2010). Mixing interview and questionnaire methods: Practical problems in aligning data. *Practical Assessment, Research & Evaluation*, *15*(1), 1 – 19. https://scholarworks.umass.edu/pare/vol15/iss1/1

Harwell, M. (2011). Research design in qualitative/quantitative/mixed methods. In C. Conrad & R. Serlin (Eds.) *The sage handbook for research in education: Pursuing ideas as the keystone of exemplary inquiry* (2nd ed.) (pp. 147 – 163). SAGE Publications. https://dx.doi.org/10.4135/9781483351377

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*, 378–405.

Hofer, B. (2012). Personal epistemology as a psychological and educational construct: An introduction. In B. Hofer & P. Pintrich (Eds.) *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 3 – 14). Lawrence Erlbaum Associates, Inc.

Hilpert, J. & Marchand, G. (2018). Complex systems research in educational psychology: Aligning theory and method. *Educational Psychologist, 53*(3), 185 – 202. https://doi.org/10.1080/00461520.2018.1469411

Hofer, B. & Bendixen, L. (2012). Personal epistemology: Theory, research, and future directions. In K. Harris, S. Graham, T. Urdan, C. McCormick, G. Sinatra, & J. Sweller (Eds.) *APA educational psychology handbook, Vol 1: Theories, constructs, and critical issues* (pp. 227 – 256). American Psychological Association. https://psycnet.apa.org/doi/10.1037/13273-000

Hofer, B. & Pintrich, P. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88 – 140. https://doi.org/10.3102%2F00346543067001088

Holloway, I., & Todres, L. (2003). The status of method: Flexibility, consistency and coherence. *Qualitative Research, 3,* 345–357. https://doi.org/10.1177%2F1468794103033004

Huling, M. (2014). *The effect of teachers' epistemological beliefs on practice* (Doctoral Thesis). Available from Scholar Commons at https://scholarcommons.usf.edu/etd/5044

Johnson, R., & Onwuegbuzie, A. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14 – 26. https://doi.org/10.3102%2F0013189X033007014

Jones, M. G. & Leagon, M. (2014) Science teacher attitudes and beliefs: Reforming practice. In N. G. Lederman & S. K. Abell (Eds.) *Handbook of research on science education, Volume II* (pp. 830 – 847). Routledge. https://doi.org/10.4324/9780203097267

Jongsma, C. (2001). Mathematization and modern science. In Howell, R. & Bradley, J. (Eds.) *Mathematics in a post-modern age: A Christian perspective* (pp. 162 – 192). Wm. B. Eerdmans Pub.

Kang, N. & Wallace, C. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. *Science Education, 89*(1), 140 – 165. https://doi.org/10.1002/sce.20013

Karam, R., Uhden, O., & Höttecke, D. (2019). The "math as prerequisite" illusion: Historical considerations and implications for physics teaching. In G. Pospiech, M. Michelini & B. Eylon (Eds.) *Mathematics in physics education* (pp. 37 - 52). Springer. https://doi.org/10.1007/978-3-030-04627-9

Kelly, A. M., & Sheppard, K. (2010). The relationship between the urban small schools movement and access to physics education. *Science Educator, 19*(1), 14 – 25. https://eric.ed.gov/?id=EJ874150

Kind, V. & Chan, K. K. H. (2017). Resolving the amalgam: Connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education, 41*(7), 964 – 978. https://doi.org/10.1080/09500693.2019.1584931

King, N. (2004). Using templates in the thematic analysis of text. In C. Cassell & G. Symon (Eds.), *Essential guide to qualitative methods in organizational research* (pp. 257–270). SAGE. http://dx.doi.org/10.4135/9781446280119

Kitchener, K. (1983). Cognition, metacognition, and epistemic cognition: A three level model of cognitive processing. *Human Development, 26*, 222 – 232. https://www.jstor.org/stable/26764585

Kitchener, R. (2002). Folk epistemology: An introduction. *New Ideas in Psychology, 20*(2-3), 89 – 105. https://psycnet.apa.org/doi/10.1016/S0732-118X(02)00003-X

Korthagen, F. (2017). Inconvenient truths about teacher learning: Towards professional development 3.0. *Teachers and Teaching, 23*(4), 387 – 405. https://doi.org/10.1080/13540602.2016.1211523

Korstjens, I. & Moser, A. (2018) Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing, *European Journal of General Practice*, *24(*1), 120-124, https://doi.org/10.1080/13814788.2017.1375092

Krey, O. (2019). What is learned about the roles of mathematics in physics while learning physics concepts? A mathematics sensitive look at physics teaching and learning. In G.

Pospiech, M. Michelini & B. Eylon (Eds.) *Mathematics in physics education* (pp. 103 - 125). Springer. https://doi.org/10.1007/978-3-030-04627-9

Kuhn, T. (1996). *The structure of scientific revolutions* (3rd Ed.). University of Chicago Press.

Kwok, P. (2014). The role of context in teachers' concerns about the implementation of an innovative curriculum. *Teaching and Teacher Education, 38*, 44 – 55. https://doi.org/10.1016/j.tate.2013.11.002

Larkin, D., Carletta, A., & Dwyer, A. (2019, April). *A longitudinal study of changes in secondary science teachers' conceptions of teaching science.* Poster presented at the Annual Meeting of the American Educational Research Association, Toronto, ON.

Lather, P. (2006). Paradigm proliferation as a good think to think with: Teaching research in education as a wild profusion. *International Journal of Qualitative Studies in Education, 19*(1), 35 – 57. https://doi.org/10.1080/09518390500450144

Le Fevre, D. (2014). Barriers to implementing pedagogical change: The role of teachers' perceptions of risk. *Teaching and Teacher Education, 38,* 56 – 64. https://doi.org/10.1016/j.tate.2013.11.007

Leininger, M. (1992). Current issues, problems, and trends to advance qualitative paradigmatic research methods for the future. *Qualitative Health Research, 2*, 392–415. https://doi.org/10.1177%2F104973239200200403

Leng, C., Abedalaziz, N., Orleans, A. V., Naimie, Z., & Islam, A. (2018). Teaching practices of Malaysian science teachers: Role of epistemic beliefs and implicit intelligence. *Malaysian Online Journal of Educational Sciences, 6*(2), 48 – 59. https://mojes.um.edu.my/article/view/12445

Leung, W. A. (2008). Teacher concerns about curriculum reform: The case of project learning. *Asia-Pacific Education Researcher, 17*(1), 75 – 97. https://login.ezproxy.library.ualberta.ca/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ehh&AN=35904663&site=ehost-live&scope=site

Lofland, J., Snow, D., Anderson, L., & Lofland, L- (2006). *Analyzing social settings. A guide to qualitative observation and analysis.* Wadsworth/Thomson Learning.

Lohse-Bossenz, H., Billion-Kramer, T., & Grunig, F. (2019, April). *Developing subject-specific teaching beliefs: The mediating role of teachers' domain-specific epistemic beliefs* [Paper presentation]. Annual Meeting of the American Educational Research Association, Toronto, Canada.

Lortie, D. (1975). *Schoolteacher*. University of Chicago Press.

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist, 39*(1), 57 – 68. https://doi.org/10.1207/s15326985ep3901_6

Lowe, B. & Appleton, K. (2015). Surviving the implementation of a new science curriculum. *Research in Science Education, 45*(6), 841 – 866. https://doi.org/10.1007/s11165-014-9445-7

Lyons, J. (2006). The Saskatchewan way: Henry Janzen and curriculum reform in Saskatchewan. In B. Noonan, D. Hallman & M. Scharf (Eds.) *A history of education in Saskatchewan: Selected readings* (pp. 51 – 60). Canadian Plains Research Center, University of Regina.

Maggioni, L. & Parkinson, M. M. (2008). The role of teacher epistemic cognition, epistemic beliefs, and calibration in instruction. *Educational Psychology Review, 20*(4), 44 – 461. https://doi.org/10.1007/s10648-008-9081-8

Maguire, M., & Delahunt, B. (2017). Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. *All Ireland Journal of Higher Education*, *9*(3), 3351 – 33514. http://ojs.aishe.org/index.php/aishe-j/article/view/335

Mansour, N. (2013). Consistencies and inconsistencies between science teachers' beliefs and practices. *International Journal of Science Education, 35*(7), 1230 – 1275. https://doi.org/10.1080/09500693.2012.743196

Mäntylä, T. & Nousiainen, M. (2014). Consolidating pre-service physics teachers' subject matter knowledge using didactical reconstructions. *Science & Education, 23*, 1583 – 1604. https://doi.org/10.1007/s11191-013-9657-7

Markic, S. & Eilks, I. (2012). A comparison of student teachers' beliefs from four different science teaching domains using a mixed methods design. *International Journal of Science Education, 34*(4), 589 – 608. https://doi.org/10.1080/09500693.2011.608092

Mathison, S. (1988). Why triangulate? *Educational Researcher, 17*(2), 13 – 17. https://doi.org/10.3102%2F0013189X017002013

McComas, W. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics, 96*(1), 10 – 16. https://doi.org/10.1111/j.1949-8594.1996.tb10205.x

McConaghy, T. (1990). Curriculum reform in Saskatchewan. *The Phi Delta Kappan, 71*(6), 493 – 494. https://www.jstor.org/stable/20404188

McCrudden, M., Marchand, G., & Schutz, P. (2019). Mixed methods in educational psychology. Contemporary *Educational Psychology, 57*, 1-8. https://doi.org/10.1016/j.cedpsych.2019.01.008

McKenzie, H. (1994). *Education in Canada: Current issues*. Library of Parliament, Research Branch. http://publications.gc.ca/Collection-R/LoPBdP/BP/bp386-e.htm

McLelland, C. (2006). The nature of science and the scientific method. *The Geological Society of America*. http://www.geosociety.org/educate/NatureScience.pdf

Meltzer, D. & Otero, V. (2015). A brief history of physics education in the United States. *American Journal of Physics, 83*(5), 447 – 458. https://doi.org/10.1119/1.4902397

Merk, S., Rosman, T., Rueb, J., Syring, M., & Schneider, J. (2017). Pre-service teachers' perceived value of general pedagogical knowledge for practice: Relations with epistemic beliefs and source beliefs. *PLoS ONE, 12*(9), e0184971. https://doi.org/10.1371/journal.pone.0184971

Milford, T., Jagger, S., Yore, L., & Anderson, J. (2010). National influences on science education reform in Canada. *Canadian Journal of Science, Mathematics and Technology Education, 10*(4), 370 – 381. https://doi.org/10.1080/14926156.2010.528827

Milford, T., & Tippett, C., (2019). Introduction: Setting the scene for a meso-level analysis of Canadian science education. In C. Tippett & T. Milford (Eds.) *Science education in Canada: Consistencies, commonalities, and distinctions* (pp. 1 - 12). Springer. https://doi.org/10.1007/978-3-030-06191-3

Ministry of Education. (2015). *Science 10 Curriculum.* Regina, SK: Ministry of Education. https://www.edonline.sk.ca/webapps/moe-curriculum-BB5f208b6da4613/CurriculumHome?id=63

Molnar, T., Elliott, D., & McVittie, J. (2019). Science education in Saskatchewan: Inquiry and indigenizing. In C. Tippett & T. Milford (Eds.) *Science education in Canada:*

Consistencies, commonalities, and distinctions (pp. 65 – 84). Springer. https://doi.org/10.1007/978-3-030-06191-3

Moore, C. (2018). *Creating scientists: Teaching and assessing science practice for the NGSS.* Routledge.

Moshman, D. (2015). *Epistemic cognition and development: The psychology of truth and justification*. Psychology Press.

Murphy, P., & Alexander, P. (2016). Interrogating the relation between conceptual change and epistemic beliefs. In J. Greene, W. Sandoval & I. Braten (Eds.) *Handbook of epistemic cognition* (439-459). Routledge. https://doi.org/10.4324/9781315795225

Murphy, P. K., Alexander, P., Greene, J., & Hennessey, M. (2012). Examining epistemic frames in conceptual change research: Implications for learning and instruction. *Asia Pacific Education Review, 13*, 475-486. http://dx.doi.org/10.1007/s12564-011-9199-0

Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology*, *33*(2), 177–208. https://doi.org/10.1016/j.cedpsych.2006.10.012

Muis, K., Bendixen, L., & Haerle, F. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18*, 3 – 54. https://doi.org/10.1007/s10648-006-9003-6

Muis, K., R., Chevrier, M., & Singh, C. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist, 53*(3), 165 – 184. https://doi.org/10.1080/00461520.2017.1421465

Muis, K. & Geirus, B. (2014). Beliefs about knowledge, knowing and learning: Differences across knowledge types in physics. *The Journal of Experiemental Education, 82*(3), 408 – 430. https://doi.org/10.1080/00220973.2013.813371

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39,* 168-183. https://doi.org/10.1016/j.learninstruc.2015.06.003

Mulhall, P., & Gunstone, R. (2008). Views about physics held by physics teachers with differing approaches to teaching physics. *Research in Science Education, 38*(4), 435 – 462. https://doi.org/10.1007/s11165-007-9057-6

Musser, G. (2019). The search for truth in physics: How close can physics bring us to a truly fundamental understanding of the world? *Scientific American, 321*(3), 30 – 34. https://www.scientificamerican.com/article/the-search-for-truth-in-physics/

Natanasabapathy, P., & Maathuis-Smith, S. (2019). Philosophy of being and becoming: A transformative learning approach using threshold concepts. *Educational Philosophy and Theory, 51*(4), 369 – 379. https://doi.org/10.1080/00131857.2018.1464439

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Nehmeh, G., & Kelly, A. M. (2018). Urban science teachers in isolation: Challenges, resilience, and adaptive action. *Journal of Science Teacher Education, 29*(6), 527–549. https://doi.org/10.1080/1046560X.2018.1474425

Nowell, L., Norris, J., White, D., & Moules, N. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*, 1 – 13. https://doi.org/10.1177%2F1609406917733847

Ogodo, J. (2019). Comparing advanced placement physics teachers experiencing physics-focused professional development. *Journal of Science Teacher Education, 30*(6), 639 – 665. https://doi.org/10.1080/1046560X.2019.1596720

Oguoma, E., Jita, L. & Jita, T. (2019) Teachers' concerns with the implementation of practical work in the physical sciences curriculum and assessment policy statement in South Africa. *African Journal of Research in Mathematics, Science and Technology Education, 23*(1), 27-39. https://doi.org/10.1080/18117295.2019.1584973

Olafson, L. & Schraw, G. (2010). Beyond epistemology: Assessing teachers' epistemological and ontological worldviews. In L. Bendixen & F. Feuch (Eds.) *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 516 – 552). Cambridge University Press. https://doi.org/10.1017/CBO9780511691904

Onwuegbuzie, A., & Dickinson, W. (2008). Mixed methods analysis and information visualization: Graphical display for effective communication of research results. *The Qualitative Report, 13*(2), 204–225. https://files.eric.ed.gov/fulltext/EJ800300.pdf

Onwuegbuzie, A., & Leech, N. (2005). Taking the "Q" out of research: Teaching research methodology courses without the divide between quantitative and qualitative paradigms. *Quality & Quantity, 39*, 267 – 296. https://doi.org/10.1007/s11135-004-1670-0

Onwuegbuzie, A. & Leech, N. (2007). Validity and qualitative research: An oxymoron? *Quality & Quantity, 41*, 233 – 249. https://doi.org/10.1007/s11135-006-9000-3

Otero, V. & Meltzer, D. (2017). The past and future of physics education reform. *Physics Today, 70*(5), 50 – 56. https://physicstoday.scitation.org/doi/10.1063/PT.3.3555

Pantic, N. (2015). A model for study of teacher agency for social justice. *Teachers and Teaching*, *21*(6), 759-778. https://doi.org/10.1080/13540602.2015.1044332

Pajares, F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*, 307 – 332. https://doi.org/10.3102%2F00346543062003307

Perimeter Institute for Theoretical Physics (2012). *EinsteinPlus* [website]. Retrieved Oct. 31, 2019 from https://www.perimeterinstitute.ca/outreach/arts-and-culture/einsteinplus

Perry, W. G. Jr. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* Holt, Rinehart and Winston.

Pekrun, R., Vogl, E., Muis, K., & Sinatra, G. (2017). Measuring emotions during epistemic activities: the epistemically-related emotions scales. *Cognition and Emotion, 31*(6), 1268 – 1276. https://doi.org/10.1080/02699931.2016.1204989

Peshkin, A. (2000). The nature of interpretation in qualitative research. *Educational Researcher, 29*(9), 5 – 9. https://doi.org/10.3102%2F0013189X029009005

Pinar, W., Reynolds, W., Slattery, P., & Taubman, P. (1995). Chapter 5: Understanding curriculum as political text. In *Counterpoints, Vol. 17* (pp. 243 – 314). Peter Lang Inc., International Academic Publishers. https://www.jstor.org/stable/42974921

Pintrich, P. (2012). Future challenges and directions for theory and research on personal epistemology. In B. Hofer & P. Pintrich (Eds.) *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 389 – 414). Routledge.

Ponnock, A. (2017). *Science teachers' epistemic cognition in instructional decision making* [Doctoral dissertation, Temple University Graduate Board]. ProQuest. https://www.proquest.com/docview/1950583609

Pospiech, G. (2019). Framework of mathematization in physics from a teaching perspective. In Pospiech, G., Michelini, M., & Eylon, B. (Eds.) *Mathematics in physics education* (pp. 1 – 38). Springer. https://doi.org/10.1007/978-3-030-04627-9

Pospiech, G., Eylon, B., Bagno, E. & Lehavi, Y. (2019). Role of teachers as facilitators of the interplay physics and mathematics. In G. Pospiech, M. Michelini & B. Eylon (Eds.) *Mathematics in physics education* (pp. 269 – 291). Springer. https://doi.org/10.1007/978-3-030-04627-9

Redish, E. (2005). *Problem solving and the use of math in physics courses* [Paper Presentation]. World View on Physics Education in 2005: Focusing on Change, Dheli, India. https://arxiv.org/pdf/physics/0608268.pdf

Redish, E. & Kuo, E. (2015). Language of physics, language of math: Disciplinary culture and dynamic epistemology. *Science & Education*, *24,* 561 – 590. https://doi.org/10.1007/s11191-015-9749-7

Redish, E., Saul, J. & Steinberg, R. (1998). Student expectations in introductory physics. *American Journal of Physics, 66*, 212 – 224. https://doi.org/10.1119/1.18847

Rimfield, K., Malanchini, M., Hannigan, L. J., Dale, P. Allen, R., Hart, S. A., Plomin, R. (2019). Teacher assessments during compulsory education are as reliable, stable, and heritable as standardized test scores. *Journal of Child Psychology and Psychiatry, 60*(12), 1288-1288. https://doi.org/10.1111/jcpp.13070

Roberts, D. (1982). Developing the concept of "curriculum emphases" in science education. *Science Education, 66*(2), 243 – 260. https://doi.org/10.1002/sce.3730660209

Robinson, S. (2006). Curriculum change in the 1980s: *Directions* and the core curriculum. In B. Noonan, D. Hallman & M. Scharf (Eds.) *A history of education in Saskatchewan: Selected readings* (pp. 209 - 219). Canadian Plains Research Center, University of Regina.

Rosman, T., & Mayer, A. K. (2018). Epistemic beliefs as predictors of epistemic emotions: Extending a theoretical model. *British Journal of Educational Psychology*, *88*(3), 410 – 427. https://doi.org/10.1111/bjep.12191

Roth, W-M., & Roychoudhury, A. (1993). The nature of scientific knowledge, knowing and learning: The perspectives of four physics students. *International Journal of Science Education, 15*(1), 27 – 44. https://doi.org/10.1080/0950069930150103

Rushton, G. T., Rosengrant, D., Dewar, A., Shah, L., Ray, H. E., Sheppard, K., & Watanbe, L. (2017). Towards a high quality high school work force: A longitudinal, demographic analysis of U.S. public school physics teachers. *Physical Review Physics Education Research, 13*(2), 0201122-1 – 020122-11. https://doi.org/10.1103/PhysRevPhysEducRes.13.020122

Ryan, G., & Bernard, H. (2000). Data management and analysis methods. In N. Denzin & Y. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 769–802). Sage.

Ryder, J. & Banner, I. (2013) School teachers' experiences of science curriculum reform, *International Journal of Science Education, (35)*3, 490-514. https://doi.org/10.1080/09500693.2012.665195

Ryder, J., Banner, I., & Homer, M. (2014). Teachers' experiences of science curriculum reform. *School Science Review, 95*(352), 126 – 130. http://eprints.whiterose.ac.uk/83044/

Sammel, A. & Zandvliet, D. (2003). Science reform or science conform: Problematic epistemological assumptions with/in Canadian science reform efforts. *Canadian Journal of Science, Mathematics and Technology Education, 3*(4), 513 – 520. https://doi.org/10.1080/14926150309556586

Saskatchewan Education. (1984). *Directions: The final report.* Department of Education. http://www.e-ajd.net/source-pdf/Directions-VOL1-eng.pdf

Saskatchewan Education. (1987). *Core curriculum plans for implementation.* Department of Education.

Saskatchewan Education. (1992). *Science: A curriculum guide for Physics 20/30.* Department of Education.

Saskatchewan Education. (1999). *Actualization of core curriculum.* Department of Education. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.628.6026&rep=rep1&type=pdf

Saskatchewan Ministry of Education. (2010). *Renewed curricula: Understanding outcomes*. Ministry of Education. https://www.edonline.sk.ca/bbcswebdav/library/curricula/English/Renewed_Curricula.pdf

Saskatchewan Ministry of Education. (2017). *Physics 30 curriculum document.* Saskatchewan Ministry of Education. https://www.edonline.sk.ca/webapps/moe-curriculum-BB5f208b6da4613/CurriculumHome?id=72

Saskatchewan Teachers' Federation. (2018). *Listen, learn, lead: Re-imagine education*. ISBN 978-1-927107-36-2. https://www.reimagineeducation.ca/

Saskatchewan Teachers' Federation. (2019). *Education re-imagined: 12 actions for education*. ISBN 978-1-927107-39-3. https://www.reimagineeducation.ca/

Schizas, D., & Psillos, D. (2019). Exploring physics teachers' NOTSs (Nature of the Sciences) conceptions and discussing their relation to the current domain-general NOS (Nature of Science) Agenda. *Electronic Journal of Science Education, 23(*2), 19 – 48. https://ejrsme.icrsme.com/article/view/18955

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498 – 504. https://psycnet.apa.org/doi/10.1037/0022-0663.82.3.498

Schommer, M. (1994a). An emerging conceptualization of epistemological beliefs and their role in learning. In R. Garner & P. Alexander (Eds.) *Beliefs about text and instruction with text* (pp. 25 - 40). Lawrence Erlbaum Associates, Inc.

Schommer, M. (1994b). Synthesizing epistemological belief research: Tentative understandings and provocative confusions. *Educational Psychology Review, 6*(4), 293 – 319. https://doi.org/10.1007/BF02213418

Schommer-Aikins, M. (2012). An evolving theoretical framework for an epistemological belief system. In B. Hofer & P. Pintrich (Eds.) *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103 – 118). Lawrence Erlbaum Associates, Inc

Schraw, G., Olafson, L., & Lunn, J. (2017). Teachers' personal epistemologies: Theoretical and practical considerations. In G. Schraw, J. Brownlee, L. Olafson, & M. Vanderveldt (Eds.) *Teachers' personal epistemologies: Evolving models for informing practice* (pp. 3 – 23). Information Age Publishing, INC.

Science Council of Canada. (1984). *Report 36 – Science for every student: Educating Canadians for tomorrow's world.* Ottawa, Ontario.

Seth, A. (2019). The neuroscience of reality: Reality is constructed by the brain and no two brains are exactly alike. *Scientific American, 321*(3), 40 – 47. https://www.scientificamerican.com/article/the-neuroscience-of-reality/

Shannon-Baker, P. & Edwards, C. (2018). The affordances and challenges to incorporating visual methods in mixed methods research. *American Behavioral Scientist, 62*(7) 935–955. https://doi.org/10.1177%2F0002764218772671

Shenton, A. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*, 63 – 75. https://doi.org/10.3233/EFI-2004-22201

Sheppard, K., Padwa, L., Kelly, A. M., & Krakehl, R. (2020). Out-of-field teaching in chemistry and physics: An empirical census study. *Journal of Science Teacher Education, 31*(7), 746-767. https://doi.org/10.1080/1046560X.2019.1702268

Sherin, B. (2001). How students understand physics equations. *Cognition & Instruction, 19*(4), 479 – 541. https://doi.org/10.1207/S1532690XCI1904_3

Shotsberger, P., & Crawford, A. (1999). On the elusive nature of measuring teacher change: An examination of the stages of concern questionnaire. *Evaluation and Research in Education, 13*(1), 3 – 17. https://doi.org/10.1080/09500799908666942

Shtulman, A. (2015). How lay cognition constrains scientific cognition. *Philosophy Compass, 10*(11), 789 – 798. https://doi.org/10.1111/phc3.12260

Siegel, H. (2014). What's in a name?: Epistemology, "epistemology," and science education. *Science Education, 98*(3), 372 – 374. https://doi.org/10.1002/sce.21104

Sikorski, T-R., & Hammer, D. (2017). Looking for coherence in science curriculum. *Science Education, 101*(6), 929-943. https://doi.org/10.1002/sce.21299

Sin, C. (2014). Epistemology, sociology, and learning and teaching in physics. *Science Education, 98*(2), 342-365. https://doi.org/10.1002/sce.21100

Sinatra, G. (2016). Thoughts on knowledge about thinking about knowledge. In J. Greene, W. Sandoval & I. Braten (Eds.) *Handbook of epistemic cognition (*479-491). Routledge. https://doi.org/10.4324/9781315795225

Sloman, S. & Fernbach, P. (2017). *The knowledge illusion: Why we never think alone.* Riverhead Books.

Slone, D. J. (2009). Visualizing qualitative information. *The Qualitative Report, 14*(3), 204 - 225. https://nsuworks.nova.edu/tqr/vol14/iss3/8

Smolin, L. (2006). *The trouble with physics: The rise of string theory, the fall of a science, and what comes next*. Houghton Mifflin Company.

Southerland, S. A, Sinatra, G. M., & Matthews, M. R. (2001). Belief, knowledge, and science education. *Educational Psychology Review, 13*(4), 325 – 351. https://doi.org/10.1023/A:1011913813847

Sulz, L. D. (2014). *Health promoting secondary schools: Implementation of a self-determination framework* [Unpublished Thesis]. University of Victoria. http://hdl.handle.net/1828/5720

Sun, C., Raptis, H., & Weaver, A. (2015). Crowding the curriculum? Changes to grades 9 and 10 science in British Columbia, 1920 – 2014. *Canadian Journal of Education, 38*(3), 1 – 31. https://www.jstor.org/stable/canajeducrevucan.38.3.11

Sunal, D., Sunal, C., Dantzler, J., Simon, M., Wooten, M., Harrell, J., & Turner, D. (2015, March). *Teaching in our physics classrooms: What students, teachers, and classroom* *observers report* [Paper Presentation]. Annual Meeting of the American Educational Research Association, Chicago, Il.

Sunal, D., Simon, M., Sunal, C., Ogodo, J., Harrell, J., & Aggarwal, M. (2019a). Effects of professional development on reform in high school physics teaching. In D. Sunal, J. Shemwell, J. Harrell & C. Sunal (Eds.) *Physics teaching and learning: Challenging the paradigm* (pp. 21 – 56). Information Age Publishing, Inc.

Sunal, C., Sunal, D., Ogodo, J., & Stephens, M. (2019b). High school physics teaching reform: Support for professional development in the literature. In D. Sunal, J. Shemwell, J. Harrell & C. Sunal (Eds.) *Physics teaching and learning: Challenging the paradigm* (pp. 1 – 20). Information Age Publishing, Inc.

Stadermann, H., Van Den Berg, E., & Goedhart, M. J. (2019). Analysis of secondary school quantum physics curricula of 15 different countries: Different perspectives on a challenging topic. *Physical Review Physics Education Research, 15*(1), 010130-1 – 010130-25. https://doi.org/10.1103/PhysRevPhysEducRes.15.010130

Tesfaye, C. L., & White, S. (2012). *Challenges high school teachers face.* AIP Statistical Research Center. https://www.aip.org/sites/default/files/statistics/highschool/hs-teacherchall-09.pdf

Tobin, K. & McRobbie, C. (1997). Beliefs about the nature of science and the enacted science curriculum. *Science & Education, 6*(4), 355 – 371. https://doi.org/10.1023/A:1008600132359

Treagust, D., Won, M., & Duit, R. (2014). Paradigms in science education research. In N. Ledermen & S. Abell (Eds.) *Handbook of research on science education, Volume 2* (pp. 3 – 17). Routledge. https://doi.org/10.4324/9780203097267

Tsai, C-C. (2002). Nested epistemologies: Science teachers' beliefs of teaching, learning and science. *International Journal of Science Education, 24*(8), 771 – 783. https://doi.org/10.1080/09500690110049132

Tsai, C-C. (2006). Teachers' scientific epistemological views: The coherence with instruction and students' views. *Science Education, 91*(2), 222 – 243. https://doi.org/10.1002/sce.20175

Tunks, J. & Weller, K. (2009). Changing practice, changing minds, from arithmetical to algebraic thinking: An application of the concerns-based adoption model (CBAM). *Educational Studies in Mathematics, 72*(2), 161 – 183. https://doi.org/10.1007/s10649-009-9189-x

Turşucu, S., Spandaw, J., Flipse, S. & Vries, M. J. (2017) Teachers' beliefs about improving transfer of algebraic skills from mathematics into physics in senior pre-university education. *International Journal of Science Education, 39*(5), 587-604. https://doi.org/10.1080/09500693.2017.1296981

Tytler, R. (2010). Stories of reform in science education: Commentary on opp(reg)ressive policies and tempered radicals. *Cultural Studies of Science Education, 5*(4), 967 – 976. https://doi.org/10.1007/s11422-010-9277-3

Uprichard, E., & Dawney, L. (2019). Data diffraction: Challenging data integration in mixed methods research. *Journal of Mixed Methods Research, 13*(1), 19 – 32. https://doi.org/10.1177%2F1558689816674650

Usher, R. (1996). A critique of the neglected epistemological assumptions of educational research. In D. Scott & R. Usher (Eds.) *Understanding educational research* (pp. 9 – 32). Routledge. https://doi.org/10.4324/9780203131923 van den Berg, R. (1993). The concerns-based adoption model in the Netherlands, Flanders, and the United Kingdom: State of the art and perspective. *Studies in Educational Evaluation, 19*(1), 51 – 63. https://doi.org/10.1016/S0191-491X(05)80056-2

van den Berg, R., Sleegers, P., Geijsel, F., & Vandenberghe, R. (2000). Implementation of an innovation: Meeting the concerns of teachers. *Studies in Educational Evaluation, 26*(4), 331 – 350. https://doi.org/10.1016/S0191-491X(00)00022-5

van den Berg, R., & Ros, A. (1999) The permanent importance of the subjective reality of teachers during educational innovation: A concerns-based approach. *American Educational Research Journal, 36*(4), 879 – 906. https://doi.org/10.3102/00028312036004879

van Driel, J., Bulte, A., & Verloop, N. (2008). Using the curriculum emphasis concept to investigate teachers' curricular beliefs in the context of educational reform. *Journal of Curriculum Studies, 40*(1), 107 – 122. https://doi.org/10.1080/00220270601078259

Walker, S., Lunn-Brownlee, J., Scholes, L., & Johansson, E. (2019). The development of children's epistemic beliefs across the early years of elementary school. *British Journal of Educational Psychology, 90*(2), 266-281. https://doi.org/10.1111/bjep.12280

Wallace, C., & Priestley, M. (2017). Secondary science teachers as curriculum makers: Mapping and designing Scotland's new curriculum for excellence. *Journal of Research in Science Teaching, 54*(3), 324 – 349. https://doi.org/10.1002/tea.21346

Watson, E. (2017). Unexpected questions: Reflecting on the teacher's experience of responding in class. *The High School Journal, 101*(1), 49 – 61. https://doi.org.10.1353/hsj.2017.0015

Watson, E. (2018). Why teach high school mathematics? Integrating mathematics with other school subjects. *Alberta Science Education Journal, 45*(3), 5 – 13. https://sc.teachers.ab.ca/SiteCollectionDocuments/ASEJ/ASEJ-Vol45No3.pdf

Watson, E. (2020). The slippery business of measuring beliefs: Lessons from a failed attempt at developing an instrument to measure teachers' epistemic beliefs about physics knowledge. *The Electronic Journal of Research in Science and Mathematics Education, 24*(2), 119 - 140. https://ejse.southwestern.edu/article/view/20294

Watson, E. & Rose, K. (2019, April). *Peering through red tape: A collaborative auto-ethnography examining barriers between teachers and educational research(ers)* [Paper Presentation]. Annual Meeting of the American Educational Research Association, Toronto, ON.

Wei, B., & Chen, N. (2019). Agency at work: Two beginning science teachers' stories in a context of reform in China. *International Journal of Science Education, 41*(10), 1287 – 1302. https://doi.org/10.1080/09500693.2019.1600205

Wheelahan, L. (2010). *Why knowledge matters in curriculum: A social realist argument.* Routledge. https://doi.org/10.4324/9780203860236

Wheeler, D. (2007). *The development and construct validation of the epistemological beliefs survey for mathematics* (Unpublished doctoral dissertation). Oklahoma State University, Stillwater, OK. https://shareok.org/handle/11244/7625

Yan, T. & Deng, M. (2019). Regular education teachers' concerns on inclusive education in China from the perspective of concerns-based adoption model. *International Journal of Inclusive Education, 23(*4), 384-404. https://doi.org/10.1080/13603116.2018.1435741

Yavuz, A. (2014). Do students trust in mathematics or intuition during physics problem solving? An epistemic game perspective. *Eurasia Journal of Mathematics, Science & Technology Education, 11*(3), 633 – 646. https://doi.org/10.12973/eurasia.2014.1205a

Yin, R.K. (2011). *Qualitative research from start to finish.* Guilford Press.

Zukav, G. (1979). *The dancing wu li masters: An overview of the new physics.* Bantam Books.

APPENDICES

Appendix A

Newton's Laws in the 1992 Physics 30 Curriculum Document

Core Unit I: Kinematics and Dynamics
F. Newton's Laws of Motion

Key Concepts

Inertia is the property of an object that resists changes in its state of rest or motion.

Inertia depends on mass. Mass is a measure of the inertia of an object.

Galileo challenged Aristotelian notions about motion by performing experiments.

Newton's first law of motion (Galileo's Principle of Inertia) describes what Galileo had discovered about inertia in his "thought experiments," using inductive reasoning.

A **net force** is the resultant of all forces acting on an object. Equilibrium exists if the net force is zero. (There must also be no resultant torque.)

An **unbalanced force** exists when the resultant of all of the forces acting on an object does not equal zero.

If no external unbalanced force acts on an object, its velocity will remain constant (*i.e.*, it will remain at rest if it was initially at rest, or continue moving in a straight line at a constant speed, if it was initially doing so).

If all of the forces acting on an object cancel one another, the resultant vector is zero and no unbalanced force exists. The object is in equilibrium.

An object at rest on a table has its weight opposed by a normal force acting on the object by the table. (Other examples of objects in static equilibrium can be used to illustrate this concept.)

If an object is moving at a constant velocity (including the possibility of being at rest) one can conclude that all of the forces acting on the object must be balanced. The net force is zero.

Many practical applications of Newton's first law are evident in common occurrences.

Inertia can be used to illustrate how objects tend to resist their state of rest or motion.

When analyzing situations involving more than one force acting on an object, it is extremely useful to represent the situation using **free body diagrams**. Vector addition can be used to determine the net force.

When a net force acts on an object, it accelerates in the direction of the net force. (Newton's second law)

$\vec{F} = m\vec{a}$

The acceleration is directly proportional to the force for a constant mass:

$\vec{a} \propto \vec{F}$

The acceleration is inversely proportional to the mass if the force is constant:

$\vec{a} \propto \frac{1}{m}$

If an object is accelerating there must be a net force acting on the object in the direction of the acceleration.

The relationship between the SI units for force and the corresponding fundamental units can be illustrated from Newton's second law.

(*i.e.*, 1 N = 1 kg m/s^2)

Newton's third law states that for every action force a reaction force exists which is equal in magnitude but opposite in direction to the action force. This can be illustrated using many common examples.

Forces exist in pairs. If object A exerts a force on object B, then object B will exert a force on object A, equal in magnitude, but opposite in direction.

There are a variety of ways of solving problems in physics. No one method is inherently superior to others, although some methods may have certain advantages in specific situations.

To solve problems relating to force and motion, geometric methods using vector diagrams, trigonometry, or vector component methods are some different ways to arrive at similar results.

Practice in problem solving leads to improved proficiency and a greater understanding of how forces interact with objects.

Free body diagrams are useful in analyzing objects in static equilibrium.

Architects, engineers, and people involved in a wide variety of other related disciplines require a thorough understanding of Newton's Laws of motion in order to design equipment which will not fail when used for the intended application.

Learning Outcomes

Students will increase their abilities to:

1. Define the following terms: inertia, free body diagram, unbalanced force, net force, inertial mass.
2. Explain what is meant by inertia.
3. State that mass is a measure of inertia.
4. State Newton's laws of motion.
5. Provide examples, illustrations, or applications of Newton's laws of motion.
6. Explain what is meant by an unbalanced force.
7. Analyze situations involving balanced and unbalanced forces on various objects with the aid of free body diagrams.
8. Recognize the importance of free body diagrams in analyzing problems in physics dealing with statics and dynamics.
9. Suggest some practical examples which illustrate the need for a thorough understanding of Newton's Laws of motion.
10. Transfer an understanding of vector addition in one or two dimensions to applications involving Newton's laws of motion.
11. Solve problems involving Newton's laws of motion.
12. Predict the direction of acceleration on an object, given the direction of the unbalanced force.
13. Predict the direction of the unbalanced force acting on an object, given the direction of the acceleration.
14. Interpret direct and inverse relationships, as they occur in Newton's second law.
15. Demonstrate an understanding of the relationship between the SI unit of force and the corresponding fundamental units.
16. Explain how the inertial mass of an object can be determined.

Teaching Suggestions, Activities and Demonstrations

1. Using an equal arm balance, determine the gravitational mass of several different objects. Place the objects on an unloaded inertial balance. Determine the period of the inertial balance for each of the objects being tested. Plot the period of the inertial mass as a function of the gravitational mass. Predict the gravitational mass of a new object after determining its inertial mass by interpolating or extrapolating on the graph. Develop a generalized conclusion about the relationship between inertial and gravitational mass.

2. Compare and contrast Aristotle's and Galileo's approach to the study of motion.

3. Describe the "thought experiments" devised by Galileo to develop the Principle of Inertia.

4. An interesting way to learn about moment of inertia is to build mobiles. For each arm of the mobile, the sum of the moments must be zero in order for it to remain in static equilibrium. This concept needs to be applied in order to build a fully balanced mobile. Each mobile could have a theme associated with it. For example, one could be a mobile illustrating Nobel Prize winners and their accomplishments. Another could illustrate common units or prefixes in the SI system, and so on. Once the mobiles have been constructed they can be hung on display in the room.

5. Load an inertial balance with a slug. Measure the period. Support the slug so it is suspended above or beneath the platform. Measure the period again and compare the results. Extend this concept to determine if an inertial balance depends upon gravity for its operation.

6. Athletic shoes are designed differently, depending on their intended sport. Research the design of several kinds of athletic shoes for different sports. Identify the important laws of physics that apply in each sport and explain how the shoes are designed to optimize performance in a particular sport.

   A similar, related activity would be to analyze other types of sports equipment in the same way.

   Much attention has been placed on using science to analyze and improve athletic performance. Some examples include blood analysis of lactic acid build up near the anaerobic threshold, max VO_2 determination, and the detection of banned masking and doping agents which enhance performance. Research some of these or other new developments in sport science.

7. Perform an activity to compare the inertial and gravitational mass of several different objects. Using an inertial balance, a double beam balance, and various different masses, the relationship between inertial mass and gravitational mass can be investigated.

8. An **inertial mass** can be measured by determining on object's acceleration. The **Principle of Equivalence** suggests that inertial and gravitational mass have the same value. Another way of stating the Principle of Equivalence is that gravity and acceleration are indistinguishable.

9. Set up a dynamics cart to a recording timer. (Students might enjoy using a skateboard instead of a dynamics cart.) Apply a constant force to the cart. Analyze the motion. Change the magnitude of the force, or change the mass of the cart (or do both) and analyze the motion. Compare the results and develop generalizations regarding the factors affecting the rate of acceleration of the cart.

   Observe safety precautions when using skateboards. Wear helmets and other protective equipment.

10. Some students might be interested in model rocketry, or there may be a club in your area. If so, class, group, or individual projects can be established. A demonstration of a model rocket launch can be performed. (Caution: Check with the Department of Transport for specific regulations regarding the use of authorized sites and other requirements.)

11. Design an experiment to determine the breaking strength of various types of monofilament fishing line. Compare the breaking point with the manufacturer's specifications.

12. Outdoors, have one student stand on a skateboard or a rotating platform. A sheet of coloured paper on the ground can be used to represent "home plate." Have a student pitcher (also standing on a skateboard) throw a ball over home plate. The batter tries to strike the ball, as in a real game of baseball. Observe the action-reaction principle at work on the pitcher and the batter. In this and the following activity, make sure protective equipment, such as elbow pads and helmets, is worn to protect students in case they fall.

    Rotational motion should be discussed briefly in conjunction with this and several other activities suggested here.

13. On a rotating platform, hold a set of dumbbells out at arm's length. Have an assistant spin you on the platform. Move the dumbbells in to your side. Ask the students to explain any noticeable change in the speed of the spin as the dumbbells are brought inward. Relate this to the change in motion of a figure skater when her or his arms are brought in toward the body while it is spinning. This helps to explain conservation of angular momentum. See the caution regarding the use of protective clothing in the previous activity.

14. Determine the mass of a metre stick. Locate the centre of gravity of the meter stick, by finding balance points on two of its flat surfaces. Support the metre stick on a fulcrum at some point other than the centre of gravity. Using a single mass, place it somewhere on the metre stick so that the rigid beam remains in static equilibrium. Discuss the concept of the sum of all moments of force (torque) equilibrating in order to maintain static equilibrium.

    Repeat several trials, supporting the beam in different positions and using different weights. Repeat using several masses at different locations. Make predictions for other trials, testing the accuracy of the predictions.

15. Set up a demonstration to illustrate the centre of gravity paradox. Tape a weight near one end of a meter stick. Try balancing the end of the meter stick on one finger, with the heavy end down, and the heavy end up.

    Students should be familiar with the idea that the lower an object's centre of gravity, the more stable it tends to be. However, in this paradox, the meter stick is easier to balance if the weighted end is closer to the top. This demonstration might lead to an interesting discussion about balance and stability.

12. The following activity can be used to explore the construction of a traditional tipi structure. The materials required are: 15 poles the size of chopsticks or larger, rope or sting, sandpaper, plasticine, cloth, round toothpicks, scissors, pen, and tape.

    Assemble the poles according to the diagram shown on the next page. Fasten with string. Cut out a cloth cover. Sew it together. Decorate the cover and attach it to the frame. Often tipi designs came from visions and dreams.

    Decide where the entrance will be. Cut an opening for the entrance. Decide how to orient the tipi, depending on the direction of the prevailing wind. Have students identify why the tipi is a stable structure in a strong wind.

    Examine the convection currents inside the tipi. This helps to explain why a fire can be lit inside the tipi.

    If students are interested in pursuing this further, they could construct a full-size replica of a tipi.

Appendix B

Epistemic Beliefs about Physics Questionnaire

The purpose of this questionnaire is to determine the beliefs of those people currently teaching Physics 30 in Saskatchewan.

Please respond to the items in terms of **your beliefs** on physics. All data analysis of the data collected with this questionnaire will be completed anonymously and reporting will also be anonymous.

Thank you for taking time to complete this task.

For the following statements, please select how relevant each statement is to you.
**Note: The statements in italics are to show readers what epistemic belief(s) each item represented when the survey was first written and were not included in the sent survey.*

	Do not agree	Generally, do not agree	Somewhat agree	Strongly agree
1. Most ideas in physics are best explained using mathematics *Physics is mathematics oriented in formulae*				
2. The laws of physics are inherent in the nature of things and independent of how humans think *Physics is absolute and unchanging*				
3. It is very difficult to separate ideas in physics since one idea can often be connected to another *Physics is a coherent system of connected ideas*				
4. Physics is best understood when it is related to the natural world *Physics is discovered from an external reality*				
5. It is important solutions in physics be clearly explained beyond solving the problem with a formula *Physics is concept oriented and qualitatively explainable*				
6. The fundamentals of physics ideas are unchanging *Physics is absolute and unchanging*				
7. Physics knowledge consists of many pieces of information, each of which applies to specific situation *Physics is a collection of isolated ideas*				
8. Mathematics is the source of factual knowledge in physics *Physics is mathematics oriented in formulae*				

	Do not agree	Generally, do not agree	Somewhat agree	Strongly agree
9. As physicists learn more, many physics ideas we use today are likely to be proven inaccurate *Physics is tentative and subject to change*				
10. Ideas in physics can be easily separated into well-defined topics *Physics is a collection of isolated ideas*				
11. There is often more than one way to interpret data in physics, thus, physics knowledge can change depend on who interprets it *Physics is tentative and subject to change* *Physics is invented based on knowers' interactions with reality*				
12. One of the most crucial skills in understanding physics is being able to explain why a formula works *Physics is concept oriented and qualitatively explainable*				
13. Physics ideas are never really proven as absolute truth *Physics is tentative and subject to change* *Physics is invented based on knowers' interactions with reality*				
14. New physics knowledge is derived from existing knowledge *Physics is a coherent system of connected ideas* *Physics is invented based on knowers' interactions with reality*				
15. Physics provides us with factual information about the natural world *Physics is discovered from an external reality*				
16. It is possible to explain ideas in physics without mathematical formulae *Physics is concept oriented and qualitatively explainable*				
17. It is important ideas in physics be accepted and approved by most physicists before they are shared with the public *Physics is absolute and unchanging*				
18. Newton's laws of motion could eventually be replaced by other laws *Physics is tentative and subject to change*				
19. Different branches of physics, like mechanics and electricity, are separate and independent of each other *Physics is a collection of isolated ideas*				
20. The laws of physics are invented based on physicists' interactions with the natural world *Physics is discovered from an external reality*				
21. It is important physics knowledge be understood as it has been derived by physicists *Physics is discovered from an external reality*				

	Do not agree	Generally, do not	Somewhat agree	Strongly agree
22. It is often possible to solve a problem in physics using more than one approach *Physics is a coherent system of connected ideas*				
23. Once an idea in physics has been verified and accepted, there is little room for argument on it *Physics is absolute and unchanging*				
24. It is vital physics knowledge be supported by mathematical proof *Physics is mathematics oriented in formulae*				
25. Methods used to solve one physics problem can only be applied to another problem if the objects involved in the two problems are identical in all respects *Physics is a collection of isolated ideas*				
26. Physics knowledge should agree with one's personal experiences in the natural world to be considered valid *Physics is invented based on knowers' interactions with reality*				
27. Physics equations do not provide an understanding of ideas in physics; they are only for doing calculations *Physics is concept oriented and qualitatively explainable*				
28. Physics knowledge makes more sense when I know the other ideas to which it is connected *Physics is a coherent system of connected ideas*				
29. When solving a problem in physics, if the calculation gives a result very different from my prediction, I trust the calculation *Physics is mathematics oriented in formulae*				

Thank you for completing this survey.
Should you have any further questions, please contact Ellen Watson at ellen.watson@ualberta.ca.

Appendix C

The Stages of Concern Questionnaire

The purpose of this questionnaire is to determine what people who are using or thinking about using the new Saskatchewan Physics 30 curriculum document are concerned about at various times during the adoption process.

Please respond to the items in terms of **your present concerns**, or how you feel about your present or potential involvement with implementing the new Saskatchewan Physics 30 curriculum document.

Thank you for taking time to complete this task.

	Irrelevant	Not true of me Now		Somewhat true of me now			Very true of me now	
	0	1	2	3	4	5	6	7
1. I am concerned about students' attitudes toward the new Saskatchewan Physics 30 curriculum document.								
2. I now know of some other approaches that might work better.								
3. I am more concerned about another changing aspect of education.								
4. I am concerned about not having enough time to organize myself each day.								
5. I would like to help other teachers in their use of the new Saskatchewan Physics 30 curriculum document.								
6. I have a very limited knowledge of the new Saskatchewan Physics 30 curriculum document.								
7. I would like to know the effect of this reorganization on my professional status (i.e., accreditation)								
8. I am concerned about conflict between my interests and my responsibilities with respect to the new Saskatchewan Physics 30 curriculum document.								
9. I am concerned about revising my use of the new Saskatchewan Physics 30 curriculum document.								

10. I would like to develop working relationships with both teachers in my school and outside of my school using the new Saskatchewan Physics 30 curriculum document.								
11. I am concerned about how the new Saskatchewan Physics 30 curriculum document affects students.								
12. I am not concerned about the new Saskatchewan Physics 30 curriculum document at this time.								
13. I would like to know who will make the decisions with the new Saskatchewan Physics 30 curriculum document.								
14. I would like to discuss the possibility of using the new Saskatchewan Physics 30 curriculum document.								
15. I would like to know what resources are available as we adopt the new Saskatchewan Physics 30 curriculum document.								
16. I am concerned about my inability to manage all that the new Saskatchewan Physics 30 curriculum document requires.								
17. I would like to know how my teaching or administration is supposed to change.								
18. I would like to familiarize other departments or persons with the progress of the new Saskatchewan Physics 30 curriculum document.								
19. I am concerned about evaluating my impact on students								
20. I would like to revise the approach of the new Saskatchewan Physics 30 curriculum document.								
21. I am preoccupied with other things than the new Saskatchewan Physics 30 curriculum document.								
22. I would like to modify our use of the new Saskatchewan Physics 30 curriculum document based on the experiences of my students.								
23. I spend little time thinking about the new Saskatchewan Physics 30 curriculum document.								
24. I would like to excite my students about their part in this new Saskatchewan Physics 30 curriculum.								
25. I am concerned about time spend working with nonacademic problems related to the new Saskatchewan Physics 30 curriculum document.								
26. I would like to know what the use of the new Saskatchewan Physics 30 curriculum document will require in the immediate future.								
27. I would like to coordinate my efforts with others to maximize the effects of the new Saskatchewan Physics 30 curriculum document.								

28. I would like to have more information on time and energy commitments required by the new Saskatchewan Physics 30 curriculum document.								
29. I would like to know what other teachers are doing in this area.								
30. Currently, other priorities prevent me from focusing my attention on the new Saskatchewan Physics 30 curriculum document.								
31. I would like to determine how to supplement, enhance, or replace the new Saskatchewan Physics 30 curriculum document.								
32. I would like to use feedback from students to change the program.								
33. I would like to know how my role will change when I am using the new Saskatchewan Physics 30 curriculum document.								
34. Coordination of tasks and people is taking too much of my time.								
35. I would like to know how the new Saskatchewan Physics 30 curriculum document is better than what we have now.								

Appendix D

Stages of Concern Questionnaire Quick Scoring Device (Hall & Hord, 2015)

The quick scoring device can be used to hand score the Stages of Concern Questionnaire (SoCQ) responses and to plot an individual profile. It is especially useful when only a small number of questionnaires need to be processed or when computer processing is not available. By following the step-by-step instructions, the SoCQ responses are transferred to the device, entered into seven scales and each scale is totaled. Then the seven raw scale score totals are translated into percentile scores and plotted on a grid to produce the individuals SoCQ profile.

Instructions

1. In the raw scoring table, transcribe each of the 35 SoCQ responses from the questionnaire (raw data). Note that the items are not in numerical order.

2. Sum the raw data for each stage in the raw scoring table and place this value in the corresponding raw score totals box. Each of these seven raw score totals is a number between 0 and 35.

3. Using the Percentile Chart for the SoCQ, find the raw scale score total for each score and record the corresponding percentile for each stage. For example, if a participant had a raw score of 11 for stage 1, the corresponding percentile is located in the row marked 11 and under the column marked stage 1 and has a value of 45. Repeat this process for stages 0 – 6 recording the value in the percentile scores row of the raw scoring table. These values are whole numbers ranging between between 0 and 99.

4. Take the percentile score for stage 0 and mark that point with a dot on the stage 0 vertical line at the appropriate height on the vertical axis. Repeat this for stages 1 – 6. Dots are then connected to create a broken line graph. This is the individual concerns profile for the participant being analyzed.

Please see the following page for the tables referred to in these instructions.

Name of Participant: _________________________

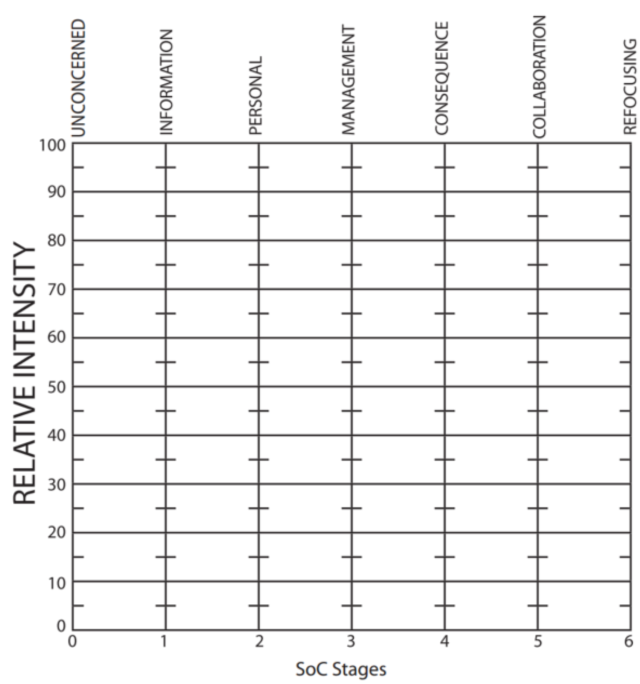
Raw Scoring Table

Stage	0		1		2		3		4		5		6	
Questions	3		6		7		4		1		5		2	
	12		14		13		8		11		10		9	
	21		15		17		16		19		18		20	
	23		26		28		25		24		27		22	
	30		35		33		34		32		29		31	
Raw Score Totals														
Percentile Scores														

Five Item Raw Scale Score Total	Percentiles for: Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
0	0	5	5	2	1	1	1
1	1	12	12	5	1	2	2
2	2	16	14	7	1	3	3
3	4	19	17	9	2	3	5
4	7	23	21	11	2	4	6
5	14	27	25	15	3	5	9
6	22	30	28	18	3	7	11
7	31	34	31	23	4	9	14
8	40	37	35	27	5	10	17
9	48	40	39	30	5	12	20
10	55	43	41	34	7	14	22
11	61	45	45	39	8	16	26
12	69	48	48	43	9	19	30
13	75	51	52	47	11	22	34
14	81	54	55	52	13	25	38
15	87	57	57	56	16	28	42
16	91	60	59	60	19	31	47
17	94	63	63	65	21	36	52
18	96	66	67	69	24	40	57
19	97	69	70	73	27	44	60
20	98	72	72	77	30	48	65
21	99	75	76	80	33	52	69
22	99	80	78	83	38	55	73
23	99	84	80	85	43	59	77
24	99	88	83	88	48	64	81
25	99	90	85	90	54	68	84
26	99	91	87	92	59	72	87
27	99	93	89	94	63	76	90
28	99	95	91	95	66	80	92
29	99	96	92	97	71	84	94
30	99	97	94	97	76	88	96
31	99	98	95	98	82	91	97
32	99	99	96	98	86	93	98
33	99	99	96	99	90	95	99
34	99	99	97	99	92	97	99
35	99	99	99	99	96	98	99

Concerns Based Systems International

Percentile Chart for the SoCQ



Individual Concerns Profile

Appendix E

General Interview Outline

1. How would you define “physics”? If you were to tell someone what physics “is” what would you tell them? If someone were to ask you what physics is about, what would you tell them?
    - What makes something an idea in physics as opposed to an idea in biology/chemistry/mathematics? What makes something distinctly physics? What about your definition could you also use in describing other disciplines?
    - What is the role of mathematics in physics?

2. What do you think are the fundamental ideas in physics?
    - Why are these the most fundamental to you?
    - Do these ideas relate to each other? If so, how?
    - Can these ideas change?

3. What do you find (personally) interesting about physics (if anything)?
    - Why do you find these aspects interesting?
    - How do you know when an idea is not considered physics?
    - What sets physics apart from other disciplines?
    - What is one an idea (or topic) you consider unique to physics and why you see this topic as “in physics” versus another subject?

4. How do people come up with new ideas in physics?
    - How are new laws and theories in physics generated?

I want us to think now about the new Saskatchewan Physics 30 document… The new document came out in 2016 and I want to talk about your impressions of the document.

5. When you first read it, what did you think?
    - Tell me more about these impressions.
    - How do these impressions relate to those you had with the previous Physics 30 curriculum?
    - Were you surprised by any of the changes made to the curriculum document? If so, what were these and what surprised you about these changes?

6. Do you think physics the way it’s presented in this document matches with what you think physics is? Do you feel that your beliefs about physics are the same as those expressed by the new curriculum or different?
    - What are some examples of what is different and/or what is the same?
    - Tell me more about your reasons for this difference or similarity.
    - What physics knowledge should students encounter in Physics 30?

7. What are your questions with this new Physics 30 curriculum?
    - Tell me more about your reasons for these questions.
    - What excites you about this new Physics 30 curriculum?

8. What do you like about it?

9. What don't you like about it?
    - What are your worries about this?
    - Are/were you worried about that?

10. How have your questions with this new Physics 30 curriculum changed since you first encountered the document?
    - What do you think motivated these changes?

11. Before we finish, is there anything you would like to discuss that you haven't already mentioned?

12. Thank you for your time. Can you summarize for me what you think the most important things we discussed today are?

Appendix F

A Quantitative Quandary

In an effort to thoroughly explore teachers' epistemic beliefs about physics knowledge and their concerns about the 2017 Saskatchewan Physics 30 curriculum document, I had intended to investigate teachers' epistemic belief profiles and their stages of concern quantitatively and qualitatively before mixing these data across common frameworks. However, as I explain in this section, analyzing my quantitative data would lead me to complete this study with only qualitative data as well as highlight that research is not always as neat and tidy as published research might suggest.

In this section, I describe the development and attempted validation of a researcher-developed survey intended to measure teachers' epistemic beliefs about physics knowledge. The survey failed to validate through an initial pilot phase, with an increased sample size of Saskatchewan teachers, and when compared to epistemic profiles derived through interviews. I also discuss recruitment issues contributing to a small sample size of Saskatchewan teachers.

Unfortunately, it was not only my created survey intended to measure teachers' epistemic beliefs about physics that failed to validate; the oft-used stages of concern questionnaire also failed to validate in this study. The weak factor analysis results may have been due to small sample size or may indicate problems with the instrument design; if either of these are the case, further development and study may help validate this instrument. However, there were other contributing factors—described in Appendix G and below—which led me to question the validity of the stages of concern questionnaire in this study. Ultimately, this previously mixed-methods study proceeded using only qualitative data.

Development of a Survey to Capture Teachers' Epistemic Beliefs About Physics Knowledge[25]

Before commencing my research investigating Saskatchewan teachers' epistemic beliefs about physics knowledge and concerns about the 2017 Saskatchewan Physics 30 curriculum document, I needed a way to capture both of these constructs. I sought to engage in mixed-methods research, specifically a convergent design (as defined by Creswell, 2015) where quantitative and qualitative data would be collected and analyzed separately and then brought together in discussion. Hence, I required a quantitative method of collecting teachers' epistemic beliefs about physics knowledge and a quantitative method of collecting teachers' concerns. Research on teachers' concerns had produced a well-known resource, the Stages of Concern Questionnaire, to collect teacher concerns. However, I was unable to identify a viable questionnaire for this study in the epistemic beliefs research literature.

Studies had produced surveys to capture students' epistemic beliefs about science and physical science (e.g., Adams et al., 2006; Elby et al., 1997; Redish et al., 1998), but no survey was identified to measure teachers' epistemic beliefs about science or physics knowledge. One study, introducing the *Views about Science and Physics Achievement* survey, mentioned teachers' epistemic beliefs but was not designed to measure teachers' beliefs since it claimed that teachers' beliefs were akin to scientists and experts in science. To fill this gap in epistemic beliefs research, I sought to design a questionnaire intended to quantitatively capture teachers' epistemic beliefs about physics knowledge.

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[25] Parts of this section in the thesis have also been published in *The slippery business of measuring beliefs: Lessons from a failed attempt at developing an instrument to measure teachers' epistemic beliefs about physics knowledge* listed in my references under Watson (2020).

Prior to accepting results from any quantitative instrument, especially the newly designed instrument, DeVellis (2012) recommends validating said instrument. Following the recommendation of DeVellis—and in the tradition of quantitative instruments intended to capture epistemic beliefs as started by Schommer (1990, 1993, 1994)—I sought to validate this survey using exploratory factor analysis as has been used in the past for such purposes by Adams et al. (2006), Chevrier et al. (2019), Fischer et al. (2019), and Hofer (2000). To conduct this analysis, this instrument was piloted with pre-service teachers in Alberta and in-service science teachers across Canada before it was used with Saskatchewan Physics teachers. This section describes the design and (attempted) validation of this survey.

Development of the Survey Items and Scales Investigating Teachers' Epistemic Beliefs about Physics Knowledge. DeVellis' (2012) eight steps to developing measurement scales were applied in the creation of this survey aimed at investigating teachers' beliefs about physics. As suggested by DeVellis (2012), theory is important to the conceptualization of constructs in any scale. Using theory extracted from literature on the four areas contributing to one's beliefs about physics knowledge—as outlined in section *2.1.3.3. Epistemic Beliefs about Physics Knowledge* of this thesis—and four instruments commonly found in research about epistemic beliefs about physics[26], I created a survey investigating teachers' epistemic beliefs about physics knowledge. As I was learning about this process from prior studies, I used the strategy suggested by Adams et al. (2006) where they gleaned and modified items from multiple surveys analyzing epistemic beliefs about physics knowledge. Statements and categories for each

[26] These surveys are The *Epistemological Beliefs Assessment for Physical Sciences* (Elby et al., 1997), the *Colorado Learning Attitudes about Science Survey* (Adams et al., 2006), the *Views about Science and Physics Achievement* survey (Halloun, 1997), and the *Maryland Physics Expectations Survey* (Redish et al., 1998).

of the four existing devices were analyzed for connections to each of the four areas of epistemic beliefs about physics knowledge as conceptualized in this study. For example, in the Maryland Physics Expectation Survey (Redish et al., 1998), two categories related to the beliefs about the content of physics knowledge continuum: (a) concepts exploring student beliefs about underlying ideas and memorization in physics, and (b) math links exploring student beliefs about the role of mathematics within physics. Statements relevant to any area of any of the epistemic beliefs about physics framework used in this study were considered when writing statements included within my questionnaire intended to investigate teachers' epistemic beliefs about physics knowledge.

After identifying and organizing statements, removing redundant statements, and rephrasing some statements to address teachers' beliefs instead of physics learners' beliefs, statements were compared within each area of belief. Statements were then re-organized as aligning with one extreme of a continuum of epistemic beliefs about physics knowledge. In a few cases, statements belonged to extremes on two different continua. For example, a statement regarding one's beliefs about the structure of physics knowledge was coded as representative of either "physics knowledge as a collection of isolated ideas" or "physics knowledge as a coherent system of connected ideas". Those statements not coded strongly to either end of any of the continua of epistemic beliefs about physics knowledge were disregarded. After this process, the maximum number of statements in any coded section was four; yielding a maximum total of 8 statements for each belief area (source, structure, content, and certainty). I wrote statements for any section with less than four statements to create a total of eight statements for each of the four areas of epistemic beliefs about physics knowledge (see Table 2). Finally, statements were compared to DeVellis' (2012) criteria for contextual relevance, wording, and purpose and refined as needed.

As is common in epistemic beliefs research (e.g., Adams et al., 2006; Lohse-Bossenz et al., 2019; Muis et al., 2019; Redish et al., 1998; Schommer, 1990, 1994b; Qian & Alvermann, 1995), this survey used a Likert scale. Likert scales are thought to offer a useful way to measure beliefs (DeVellis, 2012). The Likert scale offers the chance to investigate constructs with self-reporting, since participants respond to the level of the scale which best fits their perception. A four-point Likert scale (4 = Strongly Agree, 3 = Somewhat Agree, 2 = Generally, Do Not Agree, 1 = Do Not Agree) was used for the creation of numerical, ordinal data.

The result of this process was a 29-item instrument consisting of four subscales with each subscale corresponding to one of the four aforementioned areas of belief. Each subscale had statements written to reflect each of the extreme views of each of the four areas of epistemic beliefs about physics knowledge. This survey was intended to produce an *epistemic beliefs about physics knowledge* profile which could be used to inform teacher education, professional reflection and growth, and professional development for physics teachers. The survey can be viewed in Appendix B.

Collection of Survey Pilot Data. An online version of the survey intended to capture teachers' epistemic beliefs about physics knowledge was sent to my colleagues involved in education outside of Saskatchewan (e.g., current and past graduate students, classroom teachers, school administrators, etc.) who were asked to complete the survey investigating their epistemic beliefs about physics knowledge (if they were involved in science education) and/or forward the survey to their peers who taught physics or science. Additionally, three sections of an undergraduate course focused on instructional methods in science education were given the opportunity to voluntarily participate in this pilot study. Finally, a link to the survey was posted on twitter and Canadian high school science teachers outside of Saskatchewan were invited to complete the survey. I decided to survey science teachers, as opposed to only physics teachers, since physics teachers represent a small portion of all teachers in Western Canada and I was unsure whether I could collect enough data to complete a factor analysis with this limiting parameter.

As a result of this multi-pronged recruitment approach, I received 224 fully complete surveys. This sample consisted of pre-service and in-service science teachers (N = 224; 99 male, 124 female, 1 undeclared). Preservice teachers (N = 144) made up the bulk of the collection sample. Given the significant representation of preservice teachers, resulting factor analyses were also conducted with data from only these participants; reported measures for preservice teachers are indicated using parentheses in data tables. Participants were all over the age of 20 (M=31.86, SD = 15.63) with the lowest age range being 20 – 25 (N = 109) and the highest age reported being 60 and older (N = 1). A large portion of participants indicated having a science as their primary teaching area (N = 180) and these included biology (N=75), chemistry (N = 28), general sciences (N = 36), and physics (N = 41). Another large group of participants indicated mathematics as their primary teaching area (N = 21). Other primary teaching areas reported included drama, English, physical education, religious education, and Indigenous ways of knowing. All teachers who reported a non-science primary teaching area had a science listed as a second teaching area, hence, their responses were included in this analysis.

Validating the Survey Measuring Teachers' Epistemic Beliefs about Physics Knowledge. One area of concern with quantitative methodologies is the quality of instruments used. To ensure instruments are of sufficient quality, two aspects of survey quality are often applied: (a) internal consistency (reliability) and (b) how well the survey measures the investigated constructs (validity). It is common for internal consistency to be measured with Cronbach's alpha, which indicates how closely a set of items are related. In the literature, a minimum value of Cronbach's alpha above 0.70 within epistemic belief research has been historically acceptable (e.g., Barbera et al., 2008; Markic & Eilks, 2012; van Driel et al., 2008). Unfortunately, even widely used epistemic belief surveys such as Schommer's (1990) 63-item questionnaire, rarely meet this measure of internal consistency (Chan & Elliot, 2002; Clarebout et al., 2001; Hofer & Pintrich, 1997; Wheeler, 2007).

Results from the pilot sample were analyzed to measure the validity and reliability of this survey. Regrettably, the original intended survey design, reflective of my understanding of epistemic beliefs about physics knowledge as being represented by four areas, was not validated in the survey and a three-factor solution was found. This solution included the entire removal of the area of epistemic beliefs about physics structure.

The three-factor solution also included a new factor, beliefs about authority in physics which consisted of items from what I had defined as content in physics, source of physics knowledge, and certainty in physics knowledge. Even with this three-factor solution, values of Cronbach's alpha ranged between 0.53 and 0.66, below the aforementioned acceptable limit of 0.70. These alpha values did not reflect a good measurement of survey credibility, dependability, or internal consistency. More information regarding the attempted validation of this survey can be read in Appendix G or Watson (2020).

Recruitment for Quantitative Data Collection for Saskatchewan Physics 30 Teachers

Even though quantitative researchers have debated a minimum recommended sample size, they are generally in agreement that more participants for a factor analysis results in more stable scales (Carpenter, 2018). Hoping that an increase in the sample size would address the issues that I was having with validation, I sent the electronic survey as it had been originally designed to potential Saskatchewan Physics 30 teacher participants. Only 34 participants completed the online survey, which included both the survey about teacher concerns and epistemic beliefs about physics knowledge, and this made no difference to my factor structure.

A Note on Recruitment in this Study and the Small Sample Size. As this research investigated the concerns and epistemic beliefs of Saskatchewan Physics 30 teachers, participation was limited to teachers engaging with the 2017 Physics 30 curriculum in Saskatchewan. Teachers who met these requirements were welcome to participate regardless of location in the province, gender, age, or experience, to promote equality and fairness in this study as recommended by TCPS (2014). As of 2016, D. Elliott (personal communication), science consultant for the Saskatchewan Ministry of Education, estimated 200 Physics 30 teachers in the 27 school divisions across the province.

In the fall of 2017, applications were made to 26 of the 27 eligible Saskatchewan school divisions (one division does not offer courses beyond grade 9) requesting that they forward an email to their Physics 30 teachers inviting them to participate in this study. At the same time, per my granted ethics application, I sent my colleagues teaching science (and those who may know Physics 30 teachers) in Saskatchewan an email asking that they take the survey (if eligible) and/or pass the message on to their colleagues teaching Physics 30 (snowball sampling); colleagues were happy to pass on the message but school divisions were more reticent.

Despite several emails and phone calls to persons in charge of research requests, only four of 26 school divisions agreed to pass on the email seeking participants. Of these four divisions, only one was within a major urban center. A significant impediment to participant recruitment in this research was the rejection of my request by five of the largest school divisions in Saskatchewan. Rejecting school divisions explained these refusals were due to factors such as investigating teacher beliefs is not useful research (it did not matter since teachers are required to teach the curriculum as given), teachers in their division did not have time to participate and the division was protecting their time, and that this research may demean the work of those teachers who worked so hard to put together these curriculum documents. Investigation into these rejections and their implications is the topic of another study, Watson & Rose (2019), but these five rejections (and 3 smaller school division rejections) prevented me from directly accessing approximately 100 (an estimated half of all) Physics 30 teachers in Saskatchewan.

One Last Attempt to Validate the Survey Investigating Teachers' Epistemic Beliefs about Physics Knowledge

Even with the added surveys from Saskatchewan teachers, the factor analysis was not validating the scales as conceived by the framework designed based on the literature about epistemic beliefs about physics knowledge (see Figure 1). However, as indicated by Elby (2011) and Watson (2020), traditional methods of survey validation can be difficult in beliefs research since they lack the subtle approach necessary for these investigations. It has also been recently noted that Likert scale surveys rarely measure personal epistemological beliefs adequately (Adibelli & Bailey, 2017). I attempted to validate the survey about teachers' epistemic beliefs once again with the Saskatchewan teacher data in another way. After completing the analysis of interview data (and member checks) (see *3.4.3. Analysis of Interview Data*), I compared those epistemic beliefs profiles about physics knowledge produced from interviews with those calculated from the survey intended to capture teachers' epistemic beliefs about physics knowledge. Only one teacher's epistemic beliefs as represented by the survey interpretation matched those interpreted from the interview; this was another indication of an invalid survey.

The 29-item surveys of these 14 teachers were analyzed using the original areas of belief structure and teachers assigned a beliefs profile as determined by the survey. Survey-determined belief profiles were compared to interview-based belief profiles. Results of this comparison can be seen in Table 15, with an 'X' indicating that the participant's survey results and interview results matched. Taking the interview results to be considered accurate, as they were verified by the participant, the original survey appears to be problematic in measuring teachers' beliefs about the content, source, and certainty of physics knowledge as the highest number of participants with matching results was 50% for any area of beliefs about physics. The one area of epistemic beliefs about physics knowledge that did match for all teachers' interview- and survey-profiles

Table 15

Interview Results Compared to Survey Results for Areas of Epistemic Belief about Physics Knowledge

	Area of Belief			
Participant	Content	Source	Certainty	Structure
1	X	X		X
2				X
3	X			X
4	X	X	X	X
5			X	X
6				X
7		X	X	X
8	X		X	X
9	X	X	X	X
10				X
11			X	X
12	X			X
13	X	X		X
14		X	X	X
Percentage Matching	50	43	50	100

was teachers' beliefs about the structure of physics knowledge. However, as explained in Appendix G, items from the area of beliefs about structure were removed during factor analysis as they consistently did not load or loaded with conceptually inconsistent items. In summary, the epistemic profiles interpreted from interviews rarely matched the profile produced from the survey used.

Validating the Stages of Concern Questionnaire

Validation of the Stages of Concern Questionnaire using Factor Analysis. Historically, the SoCQ has been shown to have strong content validity, meaning that it appropriately measures concerns regarding educational innovations (e.g., Charlambous & Philipou, 2010; Hall & Hord, 2015; Kwok, 2014; Yan & Deng, 2019). As explained earlier, the SoCQ was not given to the validation sample but only completed by the 34 Saskatchewan physics teachers who opted to participate. In support of this literature, Cronbach's Alpha for the 34 surveys analyzed in this study was found to be 0.84, well above the recommended value of 0.70 for SoCQ studies (see Bailey & Palsha, 1992; Berends, 2006; Cheung et al., 2001; Christou et al., 2004; Kwok, 2014; van den Berg et al., 2000; Yan & Deng, 2019). The SoCQ showed high reliability with this group of participants, indicating that the survey was likely measuring the construct of concern.

On closer inspection, however, the alpha values for the various stages of concern ranged from 0.46 to 0.75 with only one of the seven stages of concern (stage 5) reaching the acceptable Cronbach's alpha value of 0.70. These alpha values were: stage 0 ($\alpha = 0.70$), stage 1 ($\alpha = 0.46$), stage 2 ($\alpha = 0.57$), stage 3 ($\alpha = 0.63$), stage 4 ($\alpha = 0.61$), stage 5 ($\alpha = 0.75$), and stage 6 ($\alpha = 0.62$). This suggests that the SoCQ may be an internally consistent survey ($\alpha = 0.84$) but that there is a lack of internal consistency within each of the factors (or stages of concern).

Fischer et al. (2019) call on researchers to investigate whether other models of the SoCQ might be suited to these types of investigations. Fischer and colleagues found that the Hong Kong version of the SoCQ was not a good fit for use with top-down science education reform efforts as they worked with Advanced Placement Biology teachers in the United States.

Assuming this small sample is representative, this study would suggest that the SoCQ as written by Hall and Hord (2015) has similar problems with top-down science education reform. However, I recognize that a sample of 34 surveys is extremely small with which to attempt validation procedures. The reason this survey did not show good fit might be attributed to this small sample.

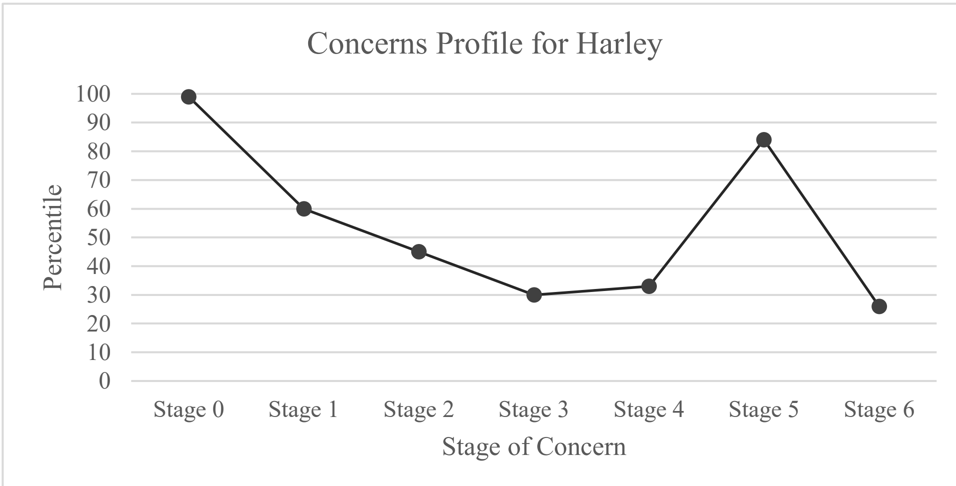
Another Attempt to Validate Using Interview Data. Survey results were analyzed according to the SoCQ quick scoring device as developed by Hall and Hord (2015), see Appendix D for this scoring device. Each individual was assigned a 'highest' stage of concern as determined by the stage with the highest relative intensity in their concerns profile. When possible, this analysis occurred for a teacher before their interview so that they might validate the findings of the survey. At the end of their interview, participants who had completed the survey were presented with a brief overview of the findings from the stages of concern questionnaire, as shown in Figure 32, and asked if they felt these results accurately represented their concerns about the curriculum document.

In addition to most (9 of 10)[27] teachers disagreeing with the calculated results of the SoCQ, the SoCQ results showed that all 10 participants had their highest concerns at stage 0.

[27] Only 10 teachers who volunteered to be interviewed completed the stages of concern questionnaire. The other six were recruited through snowball sampling and either did not complete the questionnaire or their questionnaire was not identifiable (since it was not connected to their interview participation).

Figure 32

Sample Concerns Profile



This finding implied that these teachers were unconcerned with the curriculum document and had not yet thought about the innovation (Hall & Hord, 1987, 2015). Yet, they had all been teaching with this document for at least one year. Stage 0 can be problematic for those researching mandated curriculum change because no teacher should be unaware of this innovation (Fischer et al., 2019). For example, Harley's concerns profile (Figure 32

) showed her strongest concerns in Stage 0, which would mean that she was predominantly unconcerned with the 2017 curriculum document because she was unaware of it. This Stage 0 concern was closely followed by her concern for how other teachers are using this curriculum document. These stages are not always a linear progression for teachers (Gudyanga & Jita, 2018), but it was questionable that the survey would produce a concerns profile with a focus on Stage 0 when Harley was aware of—and using—the 2017 curriculum document. Through the interviews, it was made apparent that participants were not unconcerned with the curriculum document; this is discussed in Chapter 4. When analyzed using the SoCQ quick scoring device this survey, as with the survey investigating teachers' epistemic beliefs about physics knowledge, showed an alarming amount of inconsistency.

Quantitative Questions

My survey intended to measure teachers' epistemic beliefs about physics knowledge failed to validate using my expected and research-informed factor-analysis (even with a slightly increased sample size) and when compared with qualitative results from this study. There were several reasons for me to question the reliability and validity of the researcher-designed survey intended to measure epistemic beliefs, including:

- disagreements between epistemic beliefs profiles interpreted from interviews and those epistemic beliefs profiles produced from the survey;
- the most acceptable, 3-factor solution for my validation sample only accounted for 41.4% of the variance in results; and,
- low Cronbach alpha values from the pilot survey bringing into question the internal consistency of those factors.

Following scholars such as Adibelli and Bailey (2017), Hilpert & Marchand (2018), and Elby (2011), I questioned whether epistemic beliefs can be measured quantitatively (as I had understood them to be from the literature).

I was hesitant to include my epistemic belief survey results, since reliability and validity of quantitative instruments is of great import in mixed methods research using these methods (McCrudden et al., 2019). Unfortunately, identified studies investigating epistemic beliefs about science using mixed methods (including a questionnaire or survey) either had acceptable measures of reliability and validity (e.g., Markic & Eilks, 2012; Tsai, 2006) or neglected to include any form of validation (e.g., Gu, 2016). As Anderson and Martin (2017) highlight, research publications often only “show the clean, tidy version of the research process,” (p. 1). As my quantitative research was neither “clean” nor “tidy”, I turned to the work of other dissertations for suggestions.

In the interest of transparency, and because I found it very difficult to find quantitative publications that were not presented as clean and tidy, I share my trials in quantitative research. Anderson (2017) in her thesis in Engineering and Science Education suggests maintaining and sharing an audit trail of methodological decisions (one strategy suggested by Guba & Lincoln, 1989 of ensuring credibility in research). In this section about my quantitative quandary, I have given the reader insight into my methodological decisions and on what criteria I based these decisions. As another example, Sulz (2014) described a failed validation in her doctoral thesis in Physical and Health Education. Sulz removed her self-developed scale from further analysis in her study when it failed to validate. Given my lack of confidence and that my survey had failed to validate, results from the survey intended to measure teachers’ epistemic beliefs about physics knowledge were not formally included in this study’s analysis.

After this, admittedly failed, attempt to develop and validate a survey measuring epistemic beliefs, I questioned whether epistemic beliefs were quantifiable. In the literature, epistemic beliefs are considered to consist of loosely connected dimensions (Hofer, 2000; Schommer 1994) and beliefs, in general, are a very messy construct (Pajares, 1992). Given this, “it would seem antithetical to attempt to clearly separate factors in any analysis of [epistemic] beliefs” (Watson, 2020, p. 134). Unfortunately, it is common for some educational psychology researchers to reduce complex phenomena to models meant to simplify but that fail to accurately represent phenomena (Hilpert & Marchand, 2018). Of course, one might consider other approaches of validation, such as item analysis, but I question whether this would solve the issue of separation and simplicity since many of these methods, including item response theory, also assume scale unidimensionality (as described by DeVellis, 2012). As I assert in Watson (2020), it may be that the survey designed to measure teachers' epistemic beliefs about physics knowledge was unable to validate because surveys are ill-equipped to capture, what Pajares (1992) coined as, the messy construct of beliefs.

Similar to teachers' epistemic beliefs about physics knowledge, I was left questioning whether concerns were measurable by the SoCQ. Despite the acceptable level of reliability (α = 0.84) for the SoCQ, only one stage of concern reached the acceptable level of $\alpha = 0.70$ and most (9 of 10) teachers disagreed with the results calculated from the SoCQ using the method designed by Hall & Hord (1987, 2015). Given these contradictions, I was left with doubting the credibility of the SoCQ findings. These doubts were supported by the work of Shotsberger and Crawford (1999) who cautioned against relying on using the SoCQ as a measurement of teachers' concerns since their study too found weak reliability values. Again, due to this lack of confidence, I opted to proceed without focusing on quantitative results and focus on the qualitative data collected.

Appendix G

Validation Analysis for the Survey Investigating Teachers' Epistemic Beliefs about Physics

The analytic procedures used in this study are typically used in the field of epistemic beliefs when developing, and validating, survey instruments (see, for example, Cazan, 2012; Hofer, 2000; Lin & Tsai, 2017; Schommer, 1990). Using a sample of 224 in-service and pre-service science teachers, a confirmatory factor analysis was run using AMOS using a 16, 8, and 4 factor solution, testing of the proposed model. Unfortunately, each attempt was met with an error of a negative sample moment matrix. As was commonplace in the literature (e.g., Adams et al., 2006; Schommer 1990, 1994a; Hofer, 2000; Wheeler, 2007), this researcher moved on to conduct an exploratory factor analysis to see whether an acceptable factor structure might exist. Exploratory factor analysis was conducted using principal component analysis followed by a varimax rotation. Items were included if they were above a loading value of 0.4 (per DeVellis, 2012). The Scree plot, shown in Figure 33, indicated 11 factors with eigenvalues over 1; however, as shown by the variation in eigenvalues, one can see that the graph begins to 'level out' at four or more factors, a measure often used to determine the number of factors to extract (DeVellis, 2012). As indicated by the shape of the Scree plot, it was decided that both a four and three factor solution would be considered.

Factor analysis led to the initial refinement of the initial 29-item instrument through the deletion of items and reconceptualization of subscales. As factor solutions were reviewed, items were considered for deletion if they did not load or were conceptually inconsistent with the factor on which they were loading. One example of this is the statement "Different branches of physics are separate and independent of each other", this statement was consistently loading with those statements related to the real-world connections in physics. It could be argued that the connectedness of ideas and the connectedness of concepts to the world are similar, but the researcher developing this instrument felt this statement did not connect conceptually with those statements it was loading. Another significant reduction was the removal of statements originally connected to the subscale *beliefs about physics structure*. After careful review, it was noted that of these eight statements, four consistently failed to load and the other four were conceptually inconsistent with the categories in which they loaded. As a consequence, those items initially connected to the *beliefs about physics structure* scale were removed. Items which did not load or were conceptually inconsistent with those factors on which they did load were reviewed and removed. Once acceptable factor loadings were produced, this was followed by a review of internal consistency as represented by Cronbach alpha coefficients (DeVellis, 2012).

In both the four and three factor solutions, shown in Table 16 and Table 18 respectively, areas initially included were re-assessed and, in some cases, re-conceptualized based on

Figure 33

Scree Plot of Original Data

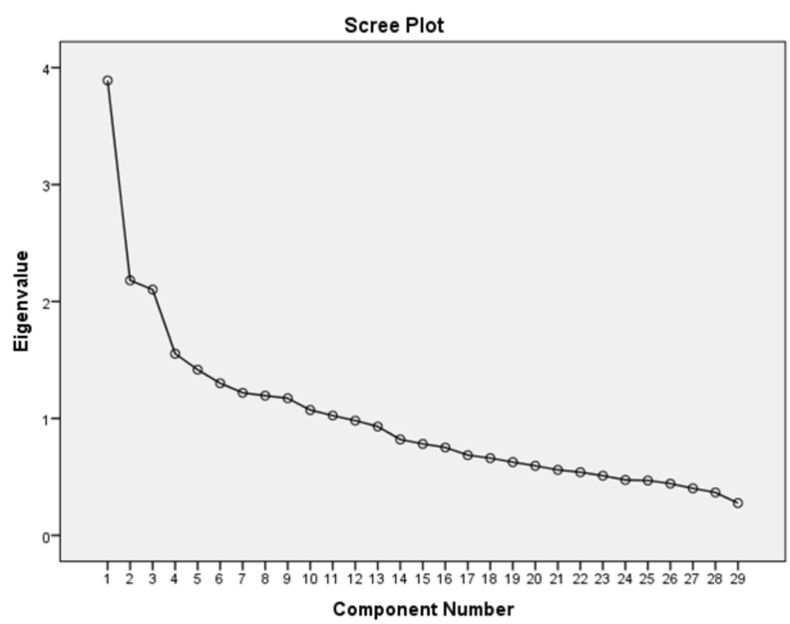


Table 16

Teachers' Epistemic Beliefs about Physics (TEBaP) Survey Items and Corresponding Factor Loadings (Explored 3 Factor Solution)

	Factor		
Item no.	Beliefs about authority	Beliefs about certainty	Beliefs about source
Q8	0.65		
Q23	0.63		
Q19	0.59		
Q24	0.56		
Q21	0.55		
Q17	0.54		
Q6	0.45		
Q18		0.74	
Q9		0.69	
Q13		0.56	
Q11		0.52	
Q4			0.72
Q5			0.71
Q28			0.64
Explained Variance	17.10%	12.51%	11.77%
Alpha Value	0.66	0.52	0.53
Response Mean	2.56	2.57	3.60
Response SD	0.78	0.87	0.57

Table 17

Description of Scales and a Sample Item for Each Scale on the Revised TEBaP

Subscale Name (Beliefs about:)	Description (Extent to which students consider:)	Sample Item(s)
authority in physics knowledge	…that physics knowledge is determined by authority, including mathematics and scientists.	Mathematics is the source of factual knowledge in physics. It is important ideas in physics be accepted and approved by most physicists before they are shared with the public.
certainty in physics knowledge	…physics knowledge is susceptible to change.	Physics ideas are never really proven as absolute truth.
the source of physics knowledge	…physics knowledge can, or should be, connect(ed) to the real world.	Physics is best understood when it is related to the natural world.

Table 18

Teachers' Epistemic Beliefs about Physics (TEBaP) Survey Items and Corresponding Factor Loadings (Explored 4 factor solution)

Item no.	Factor			
	Beliefs about authority	Beliefs about certainty	Beliefs about source	Physics Connections
Q17	0.63			
Q23	0.62			
Q8	0.57			
Q7*	0.56			
Q21*	0.55			
Q29	0.53			
Q6	0.52			
Q18		0.68		
Q9		0.66		
Q13		0.66		
Q11		0.54		
Q4			0.75	
Q5			0.69	
Q28			0.62	
Q12*				0.77
Q15*				0.61
Q24				0.51
Total Explained Variance	14.09%	11.22%	10.79%	9.89%
Cronbach's Alpha	0.68	0.55	0.53	0.42

*Indicates statement removed from 3 Factor Solution due to DNL

loadings. Both solutions indicated factors of *beliefs about authority, certainty,* and *source* of physics knowledge. The fourth factor indicated has been titled *connection* of physics knowledge as the items all speak to the explanation or connection of physics ideas with other aspects. In both the three and four factor solutions, it is noted that many of those statements initially included in the area of belief about physics content loaded with those statements considered to represent the area of belief about the source of physics knowledge. Specifically, statements written to explore the belief that physics knowledge was best represented with mathematics loaded with those statements written to explore the belief that physics knowledge was absolute and held by some external authority.

Upon review of both factor loading structure, it was determined that the three-factor structure was likely a better representation of those constructs being represented. The fourth factor, called *connection*, was both weakly correlated (α=0.42) and the items were not as conceptually consistent as within other factors. The items in this category all speak to connection but speak to a variety of connections such as those between physics and the real world and physics knowledge and mathematics. As this was the factor to disappear on the three-factor solution the selection of the three-factor structure was supported. Three subscales, representing three areas of belief, employing 14 items were derived from statistical analysis. Table 17 is a description of each of the three subscales, the belief areas they represent, and a sample item used to investigate these beliefs. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) value was 0.65; typically, a KMO-MSA value above 0.60 indicates factor analysis is appropriate for the data set (Kaiser, 1974; Wheeler, 2007). Bartlett's test of sphericity shown to be significant ($p=0.00$), and 41.4% of variance was accounted for by the three factors; explaining 17.10% of the variance (41.3% of the total variance explained) in *beliefs about authority*, 12.51% of the variance (30.2% of the total variance explained) in *beliefs about certainty,* and 11.77% of the variance (28.4% of the total variance explained) in *beliefs about source*. As shown in Table 16, each item loaded on a single factor and loading values range between 0.45 and 0.72 indicating strong factorial validity of the scale. This is also supported by finding each item focused on a specific factor, as shown in this solution.