*Alberta Journal of Educational Research, Vol. 67.1, Spring 2021, 53-67*

# Saskatchewan Physics Teachers' Epistemic Beliefs: A Glimpse Into an Under Examined Area of Teachers' Professional Education

Ellen R. Watson
University of Alberta

*Teachers' beliefs about knowledge in their subject deeply impact their classroom practice. This study analyzed the epistemic beliefs about physics knowledge held by Saskatchewan high school physics teachers using a newly designed framework of epistemic beliefs about physics knowledge. Results suggest that teachers' epistemic beliefs about physics knowledge are relatively consistent within the areas of certainty and structure of physics knowledge; most participants believed that physics knowledge was tentative and subject to change as well as coherent and connected in its structure. However, participants rarely agreed on the source and content of physics knowledge. As teachers' beliefs likely influence the way a curriculum document is interpreted and implemented, students across the province of Saskatchewan might develop very different understandings of physics knowledge due to variations in teachers' epistemic beliefs. The findings of this study provide insights into areas of professional development for teachers and pre-service teacher instruction. The article concludes with suggestions for educating teachers to better understand their own epistemic beliefs about knowledge in the subjects they teach as well as the impact these beliefs may have on their classroom.*

*Les croyances des enseignants quant à leur connaissance de la matière ont un impact important sur leur pratique pédagogique. S'appuyant sur un nouveau cadre des croyances épistémiques portant sur les connaissances en physique, cette étude a analysé les croyances épistémiques qu'ont des enseignants de la physique au secondaire en Saskatchewan quant à leurs connaissances en physique. Les résultats indiquent que les croyances épistémiques des enseignants sont relativement homogènes dans les domaines touchant la certitude et la structure des connaissances en physique, la plupart des participants ayant indiqué qu'ils croient que les connaissances en physique sont provisoires, sujettes aux changements et cohérentes et liées sur le plan structurel. Toutefois, les participants étaient rarement en accord quant à la source et au contenu des connaissances en physique. Étant donné qu'il est probable que les croyances des enseignants influencent l'interprétation et la mise en œuvre de matériel pédagogique, il se peut que les élèves de partout en Saskatchewan développent des idées très différentes des connaissances en physique en raison des variations dans les croyances épistémiques de leurs enseignants. Les résultats de cette étude permettent de mieux comprendre certains domaines du développement professionnel pour enseignants et de la formation des étudiants en pédagogie. L'article se termine par des suggestions visant une formation des enseignants qui leur permettrait de mieux comprendre leurs propres croyances épistémiques des connaissances de la matière qu'ils enseignent ainsi que l'impact que pourraient avoir ces croyances dans leur salle de classe.*

The beliefs held by a teacher about the subjects they teach are central to their practice (Hoy, Davis, & Pape, 2006) and can deeply influence how knowledge in a subject is conceived (Jones & Leagon, 2014; Moshman, 2015). Therefore, it seems important for teachers to reflect on their beliefs throughout their careers. A subject of instruction will also have ways of knowing specific to its domain (Wheelahan, 2010); for example, in the sciences, it is generally accepted that knowledge is created from the interpretation of observations and data. It may be that using discipline-specific ways of knowing, along with personal experiences, a teacher constructs an epistemic belief system of what constitutes knowledge in a subject. This belief system can operate as a lens to interpret the encountered world, including curriculum documents. Hence, teachers' epistemic beliefs about knowledge should be explored and reflected on by both educational researchers and teachers themselves.

Educational literature has investigated students' epistemic beliefs about physics knowledge (e.g., Hammer, 1994; Muis, 2008; Yavuz, 2014), yet, there is a lack of literature investigating teachers' epistemic beliefs about physics knowledge. As teachers are intimately tied to the learning process, and "[epistemic] beliefs are critical to the learning process" (Schommer, 1994b, p. 315), epistemic beliefs should be of importance to any educator. In my experience, recognizing and realizing my epistemic beliefs has been the most profound professional development I have had as both a teacher and teacher educator. As suggested by Jones and Leagon (2014), helping teachers uncover their beliefs may provide avenues through which teachers can develop as thoughtful educators and professionals. By investigating teachers' epistemic beliefs about knowledge in their subjects of instruction, we may be able to catch a glimpse of how we can support and educate our subject specialist teachers in growing as reflective educators.

## Review of Epistemic Beliefs Research

Epistemology is a branch of philosophy concerned with the theory of knowledge and learning that aims to describe how and what constitutes knowledge (Hofer & Pintrich, 1997). Researchers of epistemology often investigate the source of, certainty of, and organization of knowledge (Hofer & Bendixen, 2012; Schommer, 1994a). Epistemic beliefs can be described as beliefs related to knowing (Kitchener, 2002) or beliefs that describe one's epistemology; within these constructed belief systems, one receives information and considers knowledge.

Epistemic belief research began with the work of William Perry (1970), but it was not until the work of Marlene Schommer in the 1990s that epistemic beliefs were conceived as multi-dimensional. Schommer (1990) described epistemic beliefs as having relatively independent dimensions, unlike the single-dimension developmental sequences conceived of previously. Her model described epistemic beliefs as either naïve or sophisticated in each of four areas: Innate Ability, Simple Knowledge, Quick Learning, and Certain Knowledge. Each area was named for the corresponding naïve epistemic belief; for example, simple knowledge would range from the naïve belief that knowledge is simple and unchanging whereas a more sophisticated view would be that knowledge is complex and constantly evolving. Schommer (1990, 1994a, 1994b) paved the way for the use of multi-dimensional frameworks, as used in this study, in epistemic belief research.

Educational researchers often debate whether epistemic beliefs about knowing are domain-specific (i.e., subject-specific) or domain-independent (i.e., common across all subjects) (Hofer & Pintrich, 1997; Schommer-Aikins, 2012). Early research in epistemic beliefs considered epistemic beliefs to be domain-general (e.g., Belenky, Clinchy, Goldberger, & Tarule, 1986; Kitchener, 1983; Perry, 1970). More recently, and specifically in mathematics and science education, discipline-specific beliefs have been under investigation (Buehl & Alexander, 2005; Buehl, Alexander, & Murphy, 2002a; Hofer, 2012; Muis, Bendixen & Haerle, 2006). For example, when comparing epistemic beliefs about mathematics and history, Buehl et al. (2002b) determined that students' beliefs about both the acquisition and nature of knowledge were domain-specific to either history or mathematics. Students held more naïve beliefs about knowing in mathematics than those beliefs regarding knowing in history. Lohse-Bossenz, Billion-Kramer, and Grunig (2019) found similar results with pre-service teachers of science often sharing more naïve epistemic beliefs than those of other subjects. Epistemic beliefs have been often studied as domain-specific, particularly in science and mathematics (Hofer, 2002); therefore, it is reasonable to contend that teachers hold epistemic beliefs specific to knowledge in the discipline of physics.

Research investigating science teachers' epistemic beliefs previously focused on beliefs about teaching, instruction, and learning in science (e.g., Boz & Boz, 2014; Dolphin & Tillotson, 2015; Mansour, 2013; Tsai, 2002). Similar to Hofer and Bendixen (2012) and Hofer and Pintrich (1997), this study assumed that, even though they are undeniably connected, beliefs about learning are separable from epistemic beliefs about knowledge in a subject; however, both contribute to a person's epistemological worldview (Olafson & Schraw, 2010). Beliefs about learning, and those concerning the practice of teaching, are undoubtedly connected to one's epistemological worldview regarding the discipline of physics but the intent of this study was not to investigate teacher practice or beliefs about learning. Rather, the purpose of this research was to explore teachers' epistemic beliefs about the knowledge of the subjects that they teach.

## Epistemic Beliefs About Physics Knowledge

Studies focused on discipline-specific beliefs have often included areas common to epistemic belief research, such as beliefs about the source, certainty, and organization of knowledge (Hofer, 2000; Schommer, 1994a; Schommer-Aikins, 2012), and add content-specific knowledge. In physical sciences, this addition has been, typically, the use of mathematics as justification in the discipline (e.g., Adams et al., 2006; Halloun, 1996; Redish, Saul, & Steinberg, 1998). These four areas can be used to create a framework of a multidimensional system of beliefs similar to Schommer's (1994a) model but specific to the discipline of physics. The dimensions of this system are independent but loosely connected; that is, a teachers' beliefs about one area cannot be predicted based on their beliefs about another. A visualization of this framework of epistemic beliefs about physics knowledge is shown in Figure 1.

Epistemic beliefs about the source of knowledge in physics describe whether one sees physics knowledge as discovered from interacting with an external reality or invented within a socially constructed system. Johannes Kepler, like many 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); sentiments echoed by Leibniz, Galileo, and Descartes, all of whom were major contributors to the discipline of physics. However, the belief that physics is discovered was not held by all practitioners. Physicists such as Neils Bohr, Thomas Kuhn, and Lee Smolin each claimed that physics developed through human influence (Gregory, 1988; Kuhn, 1996; Smolin, 2006). People expressing the belief that physics is invented feel that human influence controls how we describe our world. Epistemic beliefs about the source of physics knowledge characterize whether one sees physics as discovered (i.e., held in an external reality) or invented (i.e., constructed by humanity).

Physics can be distinguished from other sciences by the substantial application of mathematics to its explanations of natural phenomena. Scholars have frequently presented knowing in physics as requiring either a mathematical (i.e., emphasizing the use of formulae) or conceptual (i.e., qualitative explanations or solutions based on an understanding of physical principles and/or intuition) understanding (Muis, 2008; Sherin, 2001; Shtulman, 2015; Sin, 2014). Hammer (1994) described content in physics as either formula centered—stemming from facts, formulae, and procedures—or made of concepts based on intuition and logic. This portrayal of epistemic beliefs about content in physics places formulae on one end of a knowing continuum and conceptual physics and employing intuition based on physical understandings, at the other (Yavuz, 2014). The discipline of physics typically blends both intuitive physics with mathematics, yet epistemic beliefs about the content of physics knowledge may be oriented towards mathematics and formulae or toward conceptual, qualitative understandings of physics.

In investigations on epistemic beliefs, participants are commonly asked whether scientific knowledge is tentative and refutable or absolute (e.g., Elby, Frederiksen, Schwarz, & White, 1997; Halloun, 1996; Halloun & Hestenes, 1998; Muis & Geirus, 2014; Tobin & McRobbie, 1997). Despite the tentative nature of physics knowledge, it is not uncommon for science teachers to teach from an unchanging and orderly knowledge structure (Burbules & Linn, 1991; Sin, 2014). Tsai (2006) found mixed responses when Taiwanese science teachers were asked about whether science knowledge was tentative. As one example, a participant in this study agreed that science knowledge could change but also felt that science operated with what she called "fundamental" knowledge that was unlikely to change. Arguably, gravity may have been considered to be fundamental knowledge to the field of physics; however, with the discovery of the Higgs Boson and recent investigations into gravity waves, our understanding of gravity has indeed changed. This area concerning the certainty of physics is one that contributes to the visualization of epistemic beliefs about physics knowledge.

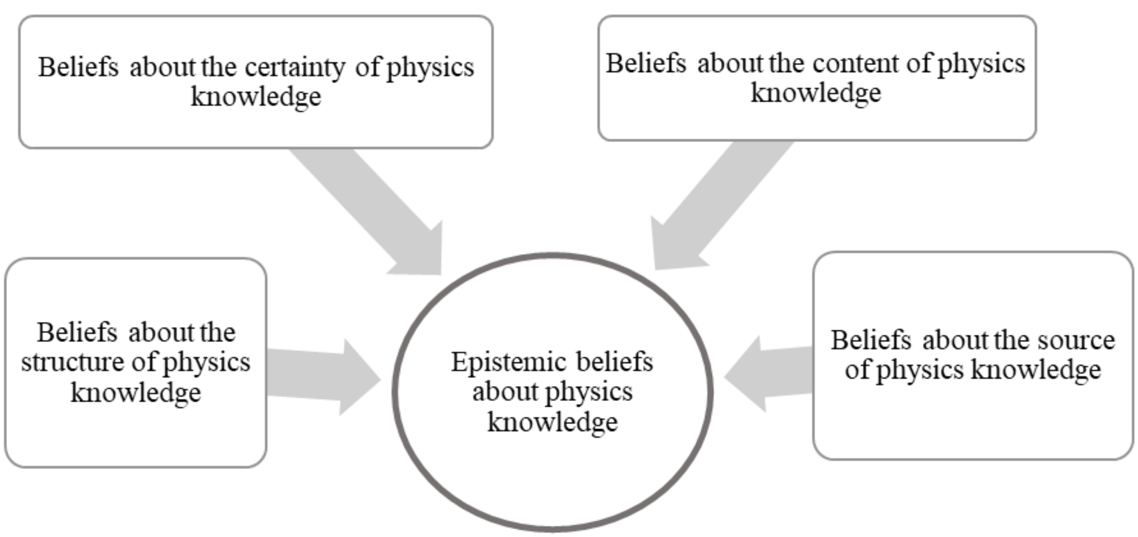


*Figure 1.* A Framework of Epistemic Beliefs about Physics Knowledge

1. Beliefs about the source of physics knowledge can be described as physics is:
    - discovered from interacting with an external reality, or
    - invented based on the social construction of the subject.
2. Beliefs about the content of physics knowledge can be described as physics is:
    - mathematics-based in formulae, or
    - concept-based and qualitative.
3. Beliefs about the certainty of physics knowledge can be described as physics is:
    - absolute and unchanging, or
    - tentative and subject to change.
4. Beliefs about the structure of physics knowledge can be described as physics is a:
    - collection of isolated ideas, or
    - a coherent system of connected ideas.

*Figure 2*. Summary of the Four Areas of Epistemic Beliefs about Physics Knowledge

Epistemic beliefs about the structure of physics knowledge indicate whether a person believes physics consists of individual, isolated pieces of information or is a coherent system of ideas. These two contrasting beliefs are often investigated within those studies on epistemic beliefs about physics or science (see Adams et al., 2006; Elby et al., 1997; Halloun & Hestenes, 1998; Hammer, 1994; Muis & Geirus, 2014). Epistemic beliefs about the structure of physics knowledge present an interesting consideration when working with physics teachers, who occupy the realm between being expert physicists, viewing physics as a coherent system of ideas, and students of physics, often viewing physics as isolated pieces of information.

Epistemic beliefs about physics knowledge can be described by the loosely connected, but independent beliefs a person holds about the source, content, certainty, and structure of physics knowledge. Figure 2 gives a summary of these four areas and their dichotomies.

## Methods

Thirty-five grade 12 physics teachers across the Western Canadian province of Saskatchewan (approximately 20% of potentially accessed teachers) completed a survey investigating teachers' beliefs about physics knowledge. From these surveys, 16 teachers volunteered to be interviewed. 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 a population over 10,000. Both female ($n$ = 5) and male ($n$ = 11) teachers were represented and experience teaching ranged from six to over 20 years. Ten teachers were accredited to teach physics in the province of Saskatchewan, meaning they had taught for at least two years and had taken a minimum of 21 university credit hours in academic courses in physics along with 3 credit hours in secondary-level curriculum science methods courses. In Saskatchewan, accredited teachers can write their final exam for grade 12 courses and do not need to participate in the provincially-administered exams for that course.

As is common with epistemic belief research (i.e., Domert, Airey, Linder, & Kung, 2007; Hammer, 1994; Roth & Roychoudry, 2007), teachers were asked about each of the four areas of epistemic beliefs about knowledge in physics using semi-structured interviews. As suggested by Guba and Lincoln (1989), a hermeneutic-dialectic method was used and participants were interviewed until data reached saturation. The designed framework of epistemic beliefs about physics knowledge, (Figure 1), was used to code interview data; data was further coded according to the dichotomies (Figure 2). Coded results were reviewed and analyzed for patterns amongst epistemic belief profiles and across teacher participants. These patterns were then compared with results from the surveys completed by Saskatchewan grade 12 physics teachers. Unique pseudonyms are used throughout the manuscript to report respondent results.

## Analysis

### Beliefs About the Structure of Physics Knowledge

Most (15 of 16) interviewed participants expressed the belief that physics knowledge is coherent and connected. Supporting the interviewed participants, 30 of 32 survey respondents disagreed with the statement “different branches of physics, like mechanics and electricity, are separate and independent of each other,” and 28 of 32 survey respondents agreed with the statement “it is very difficult to separate ideas in physics since one idea can often be connected to another.” When discussing this coherence, interviewed physics teachers often cited ideas they felt connected areas of physics knowledge. Brad, a non-accredited physics teacher with more than 20 years of teaching, said, “if you had equations that describe the positions of electrons and if you had Einstein’s gravitational field equations you could probably explain everything that happens. I think there’s some very fundamental things that will explain a lot.” This comment was echoed by interview participants Leilani and Chaz, both teaching in different urban areas, as well as Harley and Egon, both teaching in rural Saskatchewan, who all mentioned motion as the idea connecting physics knowledge. Most participants in this study believed that physics knowledge was coherent and connected.

As one caveat to the believed coherence of physics, many interviewed participants referred to the incomplete 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 Kye, Harley, and Chaz, all accredited physics teachers. Interviewed physics teachers expressed the belief that physics knowledge was coherent and connected, but many also stipulated that the field of physics is still working on this unification.

One interview participant thought that physics knowledge was made of isolated pieces of information. When first asked about whether physics ideas could be connected, Nadia, a non-accredited physics teacher working in rural Saskatchewan, said,

> I think there’s some [ideas in physics] that very related and some that you can totally separate. When we talk about the Physics 20 with the mirrors and lenses and whatever, it’s very different from the forces and motion [in Physics 30] and all of those things so I think there’s some that can be separated.

Interestingly, when probed for clarification regarding the separation of physics ideas, Nadia continued to return to 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 there is almost different things." This comment differed from those teachers discussing physics as a coherent system of ideas, who tended to refer to physics as a field of knowledge. However, Gru, an accredited physics teacher with approximately 15 years of teaching, shared that even though teachers may understand the coherence of the discipline of physics, the curriculum does not necessarily show this coherence and, consequently, many students see physics knowledge as isolated pieces of information.

> I know 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, "Don't worry about it." (Gru)

As indicated by Nadia's response and Gru's anecdote, beliefs about physics knowledge as isolated information may stem from the compartmentalized high school physics course structures. Moreover, like Gru's anecdote highlights, teachers may believe that physics knowledge is coherent but do not express this belief in class.

### Beliefs About the Certainty of Physics Knowledge

Participants consistently expressed the belief that physics, as a discipline, was tentative and likely 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 and went on to say,

> 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.

Olivia, a physics teacher who had previously worked as a field scientist, also agreed with the tentative nature of physics and claimed the idea that science (particularly physics) was unchanging was a common misconception.

> Everyone puts such an emphasis, like science is 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, yeah? So? We knew things could change.

To Olivia, experts understood that science knowledge was likely to change, whereas the public may not share the same ideal. Many interviewed teachers, like physicists (Redish et al., 1998), see the field of physics as something that regularly changes.

Even though teachers expressed the belief that physics, as a discipline, was likely to change, they were reluctant to agree that the "fundamental" ideas of physics could change. For example, one survey question, "Newton's laws of motion could eventually be replaced by other laws," split participants with 53% of respondents agreeing and 47% disagreeing with this statement. Egon, a rural physics teacher with 6-10 years' experience teaching, supported this contradiction when he stated, "some concepts of—Newton's laws and things like that—are almost a cornerstone and I couldn't foresee them [changing]." Agreeing with Egon, Kye, an accredited physics teacher working in a rural setting, claimed, "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 [physics] will change." To Kye, physics knowledge was likely to change, but he had difficulty agreeing that the "fundamental" ideas in physics would be revised. Kye's sentiments were reflected in many interviews with other participants. In addition, there was a split response to the survey item "as physicists learn more, many physics ideas we use today are likely to be proven inaccurate," with 43% of participants agreeing and 57% disagreeing with this statement. When discussing their epistemic beliefs about the certainty of physics knowledge, many teachers debated what aspects of physics were likely to change. Most teachers agreed that physics, as a discipline, was likely to change, nonetheless many felt it unlikely they would see "fundamental" ideas, such as Newton's Laws, change in physics.

## Beliefs About the Source of Physics Knowledge

Throughout the interviews, some instructors strongly expressed the belief that physics knowledge was discovered, that is, physics knowledge existed beyond human control. For example, Marcos, a physics teacher for over 20 years, explained that "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 supported by others, such as Franz who said, "you don't invent how the world works, you discover how the world works." In general, interviewed participants who expressed the belief that physics knowledge existed beyond the knower used examples rooted in the real world that they claimed could not have been invented (since they saw these examples as existing beyond our control) and cited evidence, data, and repeatability as means to generate knowledge.

On the other hand, some teachers expressed the belief that physics knowledge was invented. "Physics is invented because it's a human endeavor. So, 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," Ian mentioned, using the works of Kuhn (1996) as support. As another example, 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 discovered and they're there from the confines of our culture, our understanding of it, and our understanding of the universe." To these participants, physics knowledge was written by humans, as scientists such as Neils Bohr claimed (Gregory, 1988). Those teachers subscribing to the belief that physics knowledge was socially constructed described physics as explanations written by humans from a specific context.

Many teachers were inconsistent in their beliefs about the source of physics knowledge. It was common for participants to claim they believed physics was discovered but then make statements reflecting physics as coming from socially-constructed knowledge. 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," finally questioning herself by saying, "is that inventing something?" It appeared Leilani was not sure about what she thought about the source of physics knowledge. A similar scenario occurred with Harley who said, "I think that [physics] is discovered because, in my opinion, I think it's there 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 ambiguity was also present in survey responses, as 20 of 32 respondents agreed to one but disagreed with the other of two contradictory statements: "the laws of physics are inherent in the nature of things and independent of how humans think" and "the laws of physics are invented based on physicists' interactions with the natural world." Occasionally, instructors would catch their uncertainty in beliefs and reconsider their statements. For example, when justifying why he felt physics was discovered, Kye said,

> When Isaac Newton was coming up with the idea about gravitation between objects, he figured out something that worked. For what he could observe at the time it explained everything. Which, I guess now that I say that out loud, it's almost like he invented it to explain … yeah, that's a tough one.

It was not uncommon for instructors to have inconsistent responses when discussing their beliefs about the source of physics knowledge.

Finally, many teachers were uncertain about the source of physics knowledge. For example, Pharris, an accredited instructor in an urban center, said, "I'm kind of torn on [that topic]. I kind of feel both ways. I feel like we discovered many things that always existed, but we are also inventing it as we go." Interview participants also claimed that physics was both discovered (as it existed beyond humans) and invented (as it was socially constructed by humans). Commonly, participants referred to physics as being discovered through observation and then being invented in our attempts to explain what we found in these observations. For example, Franz, Gru, and Egon all felt that humans discover (or observe) data and phenomena and then invent models to explain these discoveries. To Brad, it was similar only he felt that "a lot of times, at first [physics ideas] are invented and then they turn into being discovered [when we observe them]." Many (but not all) of the teachers interviewed found it difficult to separate physics explanations from what they saw as truths existing in nature, waiting to be discovered. Interviewed teachers often expressed their beliefs about the source of physics knowledge as either viewing physics as discovered phenomena existing beyond the control of the knower or as the invented explanation of these phenomena.

## Beliefs About the Content of Physics Knowledge

Interviewed teachers were evenly split by their beliefs about the content of physics knowledge with eight primarily expressing the belief that physics was mathematics-based in formulae and eight indicating physics knowledge was concept-based and qualitative. Teachers' beliefs about content were characterized as tending towards mathematics- or concept-based; it was rare that a teacher expressed beliefs in only one of these two ends of the spectrum.

Notably, 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. Physics, on the other hand, was often described using terms such as "concepts," "ideas," or "the theory." Mathematics, to participants, served a purpose for, but was separate from, physics. This separation was corroborated by 27 of 32 surveyed teachers agreeing to the statement "it is possible to explain ideas in physics without mathematics." 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." Most often, teachers referred to mathematics as a tool or language used within physics to explain physical phenomena, but mathematics was not physics.

To add to this distinction, many interviewees explained that physics was about knowing how or why something works whereas mathematics was about describing what was happening. "I think physics is much more conceptual than it is a math thing … you need to understand a lot more about how physics works and it's not just about calculations," said Nadia. To Harley, this distinction between physics and mathematics manifested in the classroom and she said, "you can teach physics like a math teacher or you can teach physics like a science teacher. They can be separated because math is knowing WHAT to do whereas physics tells us why we do it." To many of the interviewed teachers, physics was about being able to explain the why or how of a situation, as Allan called it, "the theory," but this was supported by the mathematics which was used to describe what is happening.

Other teachers, believing physics knowledge was mathematics-based, often deemed mathematics as the way we knew something in physics. This way of knowing could be found in mathematics as data, quantification, factual knowledge, or proof. As an example, 23 of 32 surveyed physics teachers agreed with the statement "Mathematics is the source of factual knowledge in physics." Teachers supporting this view often indicated mathematics as being the verifying factor to the validation of physics knowledge; "I view equations in physics as the proof of concept. It's a way of showing that, not just saying that something is true but actually demonstrating or testing the theories," said Egon. His viewpoint was supported by Franz, who said, "math is what helps you justify data, justify your explanations and all that is through math." To these teachers, we justified what we know in physics through mathematics.

Finally, a lingering question for many interviewees, in both the math- and concept-based physics camps, was how deeply one can know physics without mathematics. "I would just question how deep into the world of physics you could go before you start requiring some mathematical ability," said Jens. This question was echoed by Franz, who said, "I think the deeper level of understanding [physics] is understanding the math profoundly" and Chaz, who said, "I just think that the connection [between ideas in physics] is so much greater when you know the math." It should be noted that no interviewed teacher claimed a full understanding of physics could be achieved without an understanding of mathematics, but those who felt physics was best understood conceptually often discussed the explanation of physics as a part of knowing. For example, to Harley, physics could be easily explained without mathematics (for most concepts), that is, one could know physics without mathematics but proof of physics knowledge was often in the math. Even though interviewed teachers may have believed physics knowledge is conceptual and qualitative in nature, there was still the recognition that mathematics is necessary for knowing in physics.

## Discussion

Interviewed teachers saw physics as a coherent subject when discussing it as a discipline, but often expressed the belief that physics content was isolated when discussing the high school physics curriculum document. As Harley said, "we compartmentalize information to make it more digestible," and this is certainly the case with many high school physics curriculum documents that divide physics into units such as electricity, mechanics, and forces; but is this benefitting our students? This compartmentalization misconstrues the structure of physics knowledge as a whole. Perhaps, teachers should be able to access educational opportunities that allow them to explore how connections within high school physics can be highlighted. These connections may be attempted in some pre-service education programs, yet I wonder whether teachers are truly ready to undertake this type of thinking before they are in the classroom, as many pre-service teachers are focused on mastering the "basics" teaching. As a former Saskatchewan physics teacher, it was rare I had access to any sort of physics-specific education opportunities beyond how to teach content. It may be that we need to begin considering subject-specific teacher education, which addresses areas such as teaching connections between seemingly isolated physics topics for those teachers who have already had an opportunity to deeply interact with a subject curriculum document in the classroom.

Similar to their beliefs about the structure of physics knowledge, teachers in this study were also quite consistent in their beliefs about the certainty of physics knowledge. Teachers explained physics knowledge as tentative and changing, but many added the caveat that it was unlikely for the "fundamental ideas" in physics to change. This finding corroborates those from Tsai (2006), who found that teachers believed physics ideas could change except those that were foundational to the field. To add to this, many of the ideas that teachers deemed fundamental in physics were those taught in the Saskatchewan Physics 30 course (including forces, Newton's Laws, relativity, and motion), confirming similar findings from Burbules and Linn (1991) and Sin (2014). Unfortunately, we, as physics teachers, may be inadvertently portraying physics as an unchanging discipline of knowledge. Because teachers in this study believed that physics knowledge was tentative and changing, but are teaching those ideas that "may not change," it may be beneficial for teachers to have the opportunity to learn strategies that showcase their beliefs about the tentative nature of knowledge in science, especially physics.

Interestingly, teachers were evenly split as to whether physics knowledge was mathematics-based or whether physics knowledge came from a conceptual, qualitative understanding. This split speaks to the differences we might see in physics classrooms across the province. In Saskatchewan, the grade 12 physics curriculum provides nine overarching outcomes that can be met in any way the teacher sees necessary (indicators are given as suggestions of ways these outcomes may be met). With such an open curriculum, having this variance in opinions on the content of physics means students across the province are likely to have very different experiences of physics. As Muis (2008) claimed, students often hold those beliefs emphasized by their teachers; this means students' physics education drives how the public sees the subject and with so many different belief systems educating students, it is difficult to ensure students get "the right" education (if there is such a thing) in physics. Again, providing an educational space for physics teachers to talk about the role of mathematics-based and qualitative physics in their courses may provide an opportunity for teachers to recognize their epistemic beliefs, re-visit how they teach their course, and recognize that there may not be a "right" way to view the content of physics knowledge.

Finally, interview participants often had difficulty explaining their beliefs about the source of physics knowledge. It was not uncommon for teachers to provide inconsistent responses when discussing their beliefs in this area. Many participants claimed that physics knowledge existed outside of the knower but often cited the need for community verification and agreement. This inconsistency further highlights the need for space for physics teachers to think (and learn) about those philosophical ideas behind their disciplines. Are we asking teachers, both pre-service and in-service, to explore the philosophical underpinnings of their subject? Even some accredited physics teachers struggled with clarifying their beliefs despite being deemed qualified to assess the grade 12 physics course in Saskatchewan. Also, having teachers recognize their struggles in defining the source of physics knowledge may help them to be more sensitive pedagogues to their students' struggles with the subject. This could lead to some powerful explorations at the intersection of physics and philosophy as teachers expose students to the skills of justification, questioning, and philosophical investigations. Teacher beliefs deeply influence their classrooms and students (Muis, 2008), thus it may be that teaching requirements need to expand to include education in the philosophies of their subject during and after pre-service teacher education.

Teachers who were consistent (and clear) in their beliefs about the source of physics knowledge identified the difference between physics as explanations and physics as phenomena. Responses from many participants stemmed from whether teachers saw physics knowledge as interactions (i.e., physics is discovered in the real world) or as the explanation of those interactions (i.e., physics is socially constructed). For example, Ian firmly believed that physics knowledge was socially constructed, but he addressed this muddling of the two sources by sharing,

> 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.

To Ian, physics was the story explaining the world we see. Ian had spent time reading the philosophy behind the discipline of physics, as he referenced in his interview, and this reading likely contributed to his clarity in explaining his beliefs about the source of physics knowledge. Ian and others who were clear on their beliefs provide compelling cases for the need to offer teachers of physics access to teacher education aimed at engaging them with the philosophy of physics to help teachers define their epistemic beliefs through reading and self-reflection.

## Conclusion

It is through our beliefs that we view the world (Buehl & Alexander, 2005), hence, it is important teachers are aware of their epistemic beliefs about knowledge and possess a working knowledge of how these beliefs influence their teaching. As evidenced by this research, physics teachers in some contexts may be unsure of, or inconsistent, in their epistemic beliefs about physics knowledge. I contend that a lack of firmly recognized epistemic beliefs about physics knowledge could impact the clarity with which the subject is portrayed to students. Hence, this research suggests a need for teacher education to encourage exploration of teacher epistemic beliefs about the knowledge of, and the philosophies informing, the subject they teach, in this case, physics.

I propose teacher education about subject-specific beliefs be provided, but I question its inclusion in pre-service teacher programs. All of the teachers involved in this study had more than 5 years of teaching experience and felt confident in teaching all of the content in the grade 12 physics curriculum (including the new modern physics topics introduced in 2016), yet, teachers remained inconsistent and unsure of some of their epistemic beliefs about physics knowledge. The teachers who were exceptions to this belief uncertainty had spent time over their career considering the philosophy and background of physics as a discipline. Perhaps subject-specific teacher education should resume later in the career of the teacher after they have had the opportunity to hone their "basic" teaching skills. Embarking on teacher education that is subject-specific, but not necessarily curriculum-content driven, after being in the classroom for a few years, may provide teachers with a much-needed space to encounter, learn about, and discuss epistemic beliefs and philosophies of their discipline.

## Acknowledgements

I would like to acknowledge Dr. Gregory Thomas from the Department of Secondary Education at the University of Alberta for his help in continuing to refining the ideas in this work.

## References

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

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

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. Retrieved from https://cje2.ufzg.hr/ojs/index.php/CJOE/index

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

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002a). Beliefs about academic knowledge. *Educational Psychology Review, 13*(4), 385–418. https://doi.org/10.1023/A:1011917914756

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002b). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology, 27*(3), 415–449. https://doi.org/10.1006/ceps.2001.1103

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

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. https://doi.org/10.12973/ijese.2015.228a

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

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

Gregory, B. (1988). *Inventing reality: Physics as language*. New York, NY: Wiley Science Editions.

Guba, E., & Lincoln, Y. (1989). *Fourth Generation Evaluation*. Newbury Park, CA: Sage Publications Inc.

Halloun, I. (1996, July). *Views about science and physics achievement: The VASS story*. Paper presented at the International Conference on Undergraduate Physics Education, College Park, MD. Retrieved from http://modeling.asu.edu/R&E/ICUPE96.pdf

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. Retrieved from www.jstor.org/stable/3233679
Hofer, B. (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). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
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). Washington, D.C.: American Psychological Association.
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/10.2307/1170620
Hoy, W., Davis, H., & Pape, S. (2006). Teacher knowledge and beliefs. In P. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (pp. 715–737). New York, NY: Routledge.
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). New York, NY: Routledge.
Jongsma, C. (2001). Mathematization and modern science. In R. Howell & J. Bradley (Eds.), *Mathematics in a postmodern age: A Christian perspective* (pp. 162–192). Grand Rapids, MI: Wm. B. Eerdmans Pub.
Kitchener, K. (1983). Cognition, metacognition, and epistemic cognition. *Human Development, 26*, 222–232. https://doi.org/10.1159/000272885
Kitchener, R. (2002). Folk epistemology: An introduction. *New Ideas in Psychology, 20*(2-3), 89–105. https://doi.org/10.1016/S0732-118X(02)00003-X
Kuhn, T. (1996). *The structure of scientific revolutions*. Chicago, IL: The University of Chicago Press.
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 presented at the Annual Meeting of the American Educational Research Association, Toronto, Canada. Retrieved from https://www.researchgate.net/publication/332627321_Developing_Subject-specific_Teaching_Beliefs_The_Mediating_Role_of_Teachers'_Domain-specific_Epistemic_Beliefs
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
Moshman, D. (2015). *Epistemic cognition and development: The psychology of truth and justification*. New York, NY: Psychology Press.
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., & Geirus, B. (2014). Beliefs about knowledge, knowing and learning: Differences across knowledge types in physics. *The Journal of Experimental Education, 82*(3), 408–430. https://doi.org/10.1080/00220973.2013.813371
Olafson, L. & Schraw, G. (2010). Beyond epistemology: Assessing teachers' epistemological and ontological worldviews. In L. Bendixen & F. Feucht (Eds.), *Personal Epistemology in the Classroom: Theory, Research, and Implications for Practice* (pp. 516–552). New York, NY: Cambridge University

Press.
Perry, W. G. Jr. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York, NY: Holt, Rinehart, and Winston.
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
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
Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*(3), 498–504. https://doi.org/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). Hillsdale, NJ.: 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). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
Sherin, B. (2001). How students understand physics equations. *Cognition and Instruction, 19*(4), 479–541. https://doi.org/10.1207/S1532690XCI1904_3
Shtulman, A. (2015). How lay cognition constrains scientific cognition. *Philosophy Compass, 10*(11), 789–798. https://doi.org/10.1111/phc3.12260
Sin, C. (2014). Epistemology, sociology, and learning and teaching in physics. *Science Education, 98*(2), 342–365. https://doi.org/10.1002/sce.21100
Smolin, L. (2006). *The trouble with physics: The rise of string theory, the fall of a science, and what comes next*. New York, NY: Houghton Mifflin Company.
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
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
Wheelahan, L. (2010). *Why knowledge matters in curriculum: A social realist argument*. Abingdon, Oxon: Routledge.
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

---

*Ellen R. Watson* has studied education, including a BEd and MEd at the Universities of Saskatchewan and Regina respectively. She is currently completing her Doctorate of Philosophy with the University of Alberta in the Department of Secondary Education with research interests in science education, science curriculum, and teacher beliefs. Prior to pursuing doctoral studies, Ellen was a high school teacher of science, physics, and mathematics (all streams) in Saskatchewan for 7 years.