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The Slippery Business of Measuring Beliefs: Lessons from a Failed Attempt at Developing an Instrument to Measure Teachers' Epistemic Beliefs about Physics Knowledge

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ABSTRACT

Numerous studies have been published about instruments intended to quantitatively measure students' epistemic beliefs about science; however, as this researcher would discover, developing an instrument to accurately measure epistemic beliefs about physics knowledge is not always as straightforward as the literature would make it seem. Given a lack of instruments intended to measure teachers' epistemic beliefs, this researcher endeavored to develop a valid, reliable, and theoretically grounded quantitative instrument which could measure teachers' epistemic beliefs about physics knowledge. 224 preservice and in-service teachers involved in science education completed a 29-item electronic survey developed using a literature informed framework of epistemic beliefs about physics knowledge. Results were used to quantitatively analyze the reliability and validity of this developed instrument. Additionally, as part of a parallel study, 14 of these teachers were interviewed regarding their epistemic beliefs about physics knowledge using semi-structured interviews. Using exploratory factor analysis, a mathematically valid solution was found for a 14-item version of this survey; however, the factors of this solution did not align with those commonly included in epistemic beliefs literature nor was this factor solution supported by interview results. Evidence from attempts to validate this instrument, along with a lack of alignment between survey-determined epistemic profiles and interview-determined epistemic profiles for 14 teachers, showcase the problematic nature of using standardized, quantitative approaches to measure teachers' beliefs. Findings from this study suggest that educational researchers deeply consider the nuance needed for their study prior to choosing a methodological approach to measure epistemic beliefs.

Keywords: epistemic beliefs, instrument validation, factor analysis, physics teachers

Introduction

Teachers' beliefs about their subjects deeply impact their classrooms and, consequently, the beliefs students develop about the subject of instruction (Bendixen, 2016; Bendixen & Klimow, 2019; Hofer & Pintrich, 1997; Maggioni & Parkinson, 2008; Yavuz, 2014). One's epistemic beliefs about knowledge in a subject may operate as a filter through which they read their intended curriculum document (Fives & Buehl, 2012, 2017). This changes the portrayal of what constitutes knowledge within a subject from classroom to classroom. Teachers' epistemic beliefs about knowledge influence the way knowing is portrayed in a classroom, and consequently learners' beliefs about the subject of instruction; hence, it is important teachers' epistemic beliefs about the knowledge of a subject be understood.

Beginning with the work of Marlene Schommer in the 1990's, it has become increasingly common for educational researchers to measure epistemic beliefs quantitatively. Since these early efforts, researchers have investigated students' epistemic beliefs about science, and specifically physics, through a number of quantitative instruments including 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, 1996), and the *Maryland Physics Expectations Survey* (Redish et al., 1998). These instruments are widely used with students but not typically used with teacher populations. Thus, the aim of this research was to develop a theoretically grounded, domain-specific, valid and reliable instrument to measure teachers' epistemic beliefs about physics knowledge.

This study envisioned creating a quantitative instrument able to provide teachers of physics and educators of physics teachers with a snapshot of an individual's epistemic beliefs about physics knowledge. Since teachers are rarely aware of their beliefs about (and the philosophies behind) physics (Mullhall & Gunstone, 2008), this researcher hoped that these snapshots could be used to guide teacher educators in their instruction of physics teaching methods and the nature of physics. Similarly, as research has shown a need for differentiated professional development (Borgerding et al., 2013; Gabby et al., 2017), a measurement of teachers' epistemic beliefs about physics knowledge could be useful in deciding what professional development to offer a group of physics teachers or for a teacher to make decisions about their own professional development. Finally, it was thought that a quantitative instrument that measured teachers' epistemic beliefs about physics knowledge might have been used to measure or indicate change in beliefs over a period of instruction. Each of these intended purposes were grounded in the goal of increasing teachers' awareness of their own epistemic beliefs about, and the philosophies informing, physics knowledge. Unfortunately, developing a valid and reliable instrument that accurately measured teachers' epistemic beliefs about physics knowledge would prove to not be an easy task.

Overview of Relevant Literature

Review of Epistemic Beliefs Research

Epistemology is a philosophical area concerned with one's characterization of what constitutes knowledge (Hofer & Pintrich, 1997). While epistemology does not have a single, well-constructed definition (Hofer & Pintrich, 1997; Hofer & Sinatra, 2010), researchers of epistemology are typically interested the source of, certainty of, and organization of knowledge (Hofer & Bendixen, 2012; Schommer, 1994). Epistemic beliefs can be described as those beliefs related to knowing (Kitchener, 2002) and it is within these constructed belief systems one receives information and considers knowledge.

Educational research has concerned itself with studying epistemic beliefs since the 1970s, beginning with the work of William Perry (1970), but it was not until the 1990s that epistemic beliefs were conceived as multi-dimensional and quantifiable by Marlene Schommer (1990). It is widely accepted (Hofer & Pintrich, 1997) that until Schommer's work of the 1990s, epistemic beliefs were conceptualized as developmental sequences (e.g., Perry, 1970, Belenkey et al., 1986). Schommer explained epistemic beliefs as relatively independent dimensions in her proposed model which described epistemic beliefs as either naïve or sophisticated in each of four areas: Innate Ability, Simple Knowledge, Quick Learning, and Certain Knowledge. As an example, Schommer (1990) described a naïve belief—certain knowledge—as seeing knowledge as an absolute, predetermined, and unchanging truth that, once solved, was known, whereas a more sophisticated view would be that knowledge was tentative and constantly evolving. For this model, Schommer developed a 63-item questionnaire, composed in 12 sub-sets. This work has been criticized for a lack of a consistently replicated factor structure, ambiguous wording, and low internal consistency measures (Chan & Elliott, 2002; Clarebout et al., 2001; Vecaldo, 2020; Wheeler, 2007), yet, despite criticism, this questionnaire remains one of the most widely used in quantitative measurement of epistemic beliefs.

Regardless of a lack of definition, it is common for researchers investigating epistemic beliefs to develop and use 'valid' and 'reliable' instruments intended to measure beliefs about knowledge and knowing. Following Schommer's attempt to quantify beliefs, another well-known study was conducted by Hofer (2000) who sought to validate a multidimensional, discipline-focused epistemic beliefs questionnaire. Hofer used items similar to those included in Schommer's questionnaire but aimed these items at a specific academic discipline (either psychology or science). From her validation, Hofer found a four-factor structure similar to Schommer's with four areas labelled: Certain/Simple Knowledge; Justification for Knowing; Personal, Source of Knowledge; Authority and Attainability of Truth. Her results showed these four factors as representing 63.14% of the explained variance with factor loadings ranging between 0.32 and 0.84. Although Hofer (2000) did see the merging of some factors originally conceived as separate, she concluded that there was sufficient evidence to support describing epistemic beliefs using multiple, inter-connected dimensions, and, potentially, domain specific.

Educational researchers have yet to come to a consensus regarding whether epistemic beliefs about knowledge are domain (or subject) specific or domain independent (Hofer & Pintrich, 1997; Schommer-Aikins, 2012). For example, there are researchers who question whether beliefs about knowledge are consistent across all subjects or whether people's beliefs vary in relation to different subjects (Buehl et al., 2002; Lohse-Bossenz et al., 2019). Research in epistemic beliefs, particularly at its conception, primarily considered epistemic beliefs to be unidimensional and domain general (e.g., Belenky et al., 1986; Kitchener, 1983; Perry, 1970). More recently, and specifically in mathematics and science education, discipline specific beliefs have been of interest (Buehl & Alexander, 2005; Hofer, 2012; Lohse-Bossenz et al., 2019; Muis et al., 2006). As one example, a study by Buehl et al. (2002) had students respond to items aimed at beliefs about either mathematics or history knowledge. Buehl et al. determined that students' beliefs about both the acquisition and nature of knowledge were domain specific to either history or mathematics. Typically, students held more naïve beliefs about mathematics knowledge (i.e., students typically described knowledge in mathematics as absolute and unchanging) than those held with history (i.e., students typically described knowledge in history as tentative and subject to change). Similarly, Lohse-Bossenz et al. (2019) found that preservice science teachers were more likely to have naïve epistemic beliefs when compared to preservice teachers of other subjects. As studies like this show, epistemic beliefs can be studied as domain specific, particularly in science and mathematics (Hofer, 2002). Given these studies and, since 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), it may be reasonable to investigate epistemic beliefs about knowledge specific to physics.

Research investigating science teachers' epistemic beliefs commonly focuses on beliefs in relation to teaching, instruction, and learning in science (e.g. Boz & Boz, 2014; Dolphin & Tillotson, 2015; Mansour, 2013; Tsai, 2002). It can be argued that beliefs about learning are external to beliefs about the nature of knowledge in a subject, but are clearly related, similar to the connections between epistemology and motivation, conceptual change, and metacognition (Hofer & Bendixen, 2012; Hofer & Pintrich, 1997). Following the ideals of these scholars, this researcher assumed that epistemic beliefs about learning were separate from epistemic beliefs about knowledge in physics, but both contribute to one's epistemological worldview which "consists of a set of beliefs that collectively define one's attitudes about nature and acquisition of knowledge" (Olafson & Schraw, 2010, p. 520). Beliefs about learning and those beliefs concerning the practice of teaching are undoubtedly connected to one's epistemological worldview regarding the discipline of physics. However, the intent of the instrument developed for this study was not to investigate teacher practice or beliefs about learning, but to develop and validate an instrument able to describe teachers' epistemic beliefs about physics knowledge.

Since Schommer's (1990) pursuit of a quantitative approach to epistemic beliefs measurement, it has become increasingly more acceptable to use quantitative surveys in epistemic beliefs research. Commonly used instruments include the *Epistemological Questionnaire (EQ)* (Schommer, 1990, 1993, 1998; Schommer et al, 1992; Vecaldo, 2020) and the *Revised Epistemological Questionnaire* (*REQ*) (Hofer, 2000; Qian & Alvermann, 1995). In measuring epistemic beliefs about physics, there are also four instruments often cited; these include: the *Epistemological Beliefs Assessment for Physical Sciences (EBAPS)* (Elby et al., 1997), the *Colorado Learning Attitudes about Science Survey (CLASS)* (Adams et al., 2006), the *Views about Science and Physics Achievement Survey (VASS)* (Halloun, 1996), and the *Maryland Physics Expectations Survey (MPEX)* (Redish et al., 1998). All of these instruments investigate both beliefs about learning and beliefs about the knowledge in a subject, thus, a need for an instrument able to explore epistemic beliefs about knowledge separate from learning needed to be designed for this study. Previously developed surveys were also designed to specifically measure learners' beliefs about science. The *VASS* does reference the beliefs of teachers but Halloun (1996) claimed that teachers could be considered experts in physics. Hence, to fill a need for a quantitative instrument aimed at measuring teachers' epistemic beliefs about physics knowledge, specifically those separate from beliefs about learning, this study attempted to develop such an instrument.

Theoretical Framework of Epistemic Beliefs about Physics

Studies focusing on discipline specific beliefs, particularly in sciences, often concern themselves with areas common in epistemic belief research, such as beliefs about the source, certainty, and organization of knowledge (Chevrier et al., 2019; Hofer, 2000; Schommer, 1994; Schommer-Aikins, 2012), with the addition of content specific knowledge, such as the use of mathematics in the discipline (e.g., Adams et al., 2006; Halloun, 1996; Redish et al., 1998). These four areas make up a multidimensional system of beliefs, similar to the model proposed by Schommer (1994), specific to the discipline of physics. As in the Schommer model, the dimensions of this proposed system are loosely connected, but do not depend on each other. For example, a teacher's beliefs about the source of physics knowledge could not be predicted based on an individual's beliefs about the certainty of physics knowledge. Using these areas, this study assumed that teachers' epistemic beliefs about physics knowledge were also multi-dimensional. A visualization of these areas as they contribute to the construction of one's epistemic beliefs about physics knowledge is shown in Figure 1.

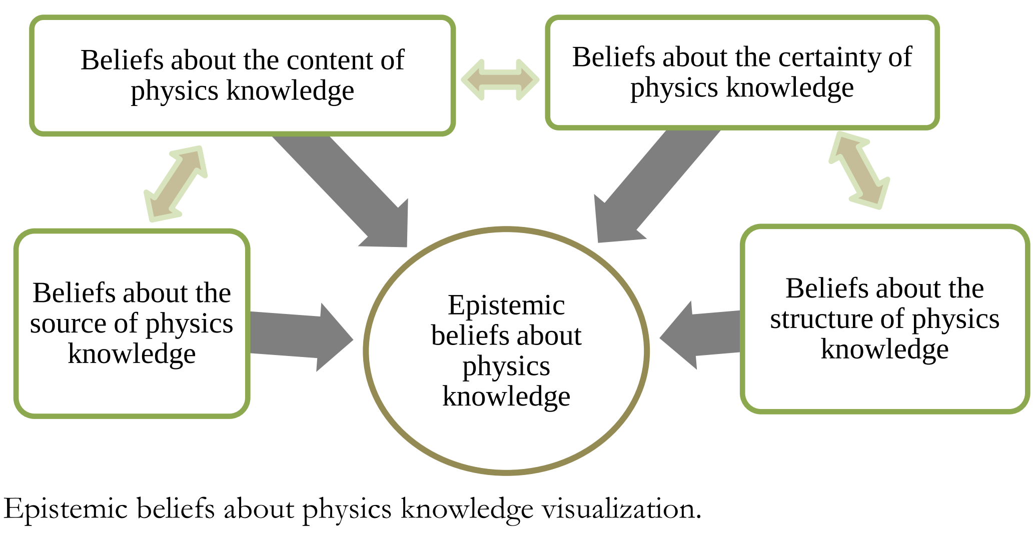

Figure 1. Epistemic beliefs about physics knowledge visualization.

It is common for studies to investigate epistemic beliefs about physics and/or science by making a distinction between physics knowledge as invented by or discovered by scientists (e.g. Adams et al., 2006; Elby et al., 1997; Muis & Geirus, 2014; Redish et al., 1998; Tobin & McRobbie, 1997). It has been claimed that the goal of any science is to explain the world based on evidence (Moshman, 2015), yet what constitutes evidence may differ for various people. For some, physics knowledge consists of pre-determined ideals and structures discovered by physicists (Davis, 2004). As one example, 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). Leibniz, Galileo, and Descartes, all of whom were major contributors to the discipline of physics, shared this belief that physics knowledge was discovered. On the other hand, it may be that physics knowledge is physical – rooted in experience and designed by humans (i.e., Burbules & Linn, 1991; Sin, 2014). According to this belief, physics knowledge is 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 is developed through human influence and by a scientific community (Gregory, 1988; Kuhn, 1996; Smolin, 2006). Beliefs about the source of physics knowledge describe the extent to which one perceives physics knowledge as discovered from an external reality or as invented by humans interacting with the world is one of four dimensions informing one's epistemic beliefs about physics knowledge.

Physics can be differentiated from other sciences by the substantial application of mathematics to its explanations of natural phenomena (Pospiech, 2019). Literature frequently presents knowledge in high school physics as focusing on either a mathematical understanding (emphasizing the use of formulae) or conceptual understanding (qualitative explanations or solutions based on an understanding of physical principles and/or intuition) (Muis, 2008; Pospiech, 2019; Sherin, 2001; Shtulman, 2015; Sin, 2014; Wei & Chen, 2019). According to Hammer (1994), in his research with first year physics students, content in physics is often either seen as formula centered – stemming from facts, formulae, and procedures – or made of concepts 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 an explanatory, intuitive solution based on a sound understanding of physical principles. 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 content in physics places formulae on one end of knowing and conceptual physics, employing intuition and qualitative explanations based on physical understandings, at the other. Schommer-Aikins (2012) suggested that these epistemic beliefs be investigated as lying on a continuum ranging between the two extremes; ideally, the instrument developed in this study would have placed teachers' beliefs along a continuum, but, first, the instrument needed to be considered valid and reliable. In any account, the discipline of physics blends intuitive physics with mathematics (Brahmia, 2014; Pospiech, 2019), epistemic beliefs about the content of physics knowledge may be oriented towards mathematics and formulae or toward conceptual, qualitative understandings of physics.

When investigating epistemic beliefs about physics knowledge, participants are commonly asked whether they perceive scientific knowledge to be tentative and refutable or absolute in nature (e.g., Elby et al., 1997; Halloun, 1996; Halloun & Hestenes, 1998; Muis & Geirus, 2014; Tobin & McRobbie, 1997; Tsai, 2006). Despite typically believing that physics knowledge is tentative, science teachers often teach from 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 in nature; for example, a participant in Tsai's study agreed that knowledge in science could change, but also felt that science operated 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 our understanding of gravity has recently changed. Whether scientific knowledge is tentative or constant is not the focus of this study, still, this area of beliefs about the certainty of physics knowledge is certainly pertinent to an individual's epistemic beliefs about physics knowledge.

Epistemic beliefs about the structure of physics knowledge can indicate whether a person believes physics knowledge consists of individual, isolated information or physics knowledge is a coherent system of ideas. This is another area commonly investigated in epistemic beliefs research in education (Hofer & Pintrich, 1997). Specifically, these two contrasting beliefs are commonly investigated within those studies investigating epistemic beliefs about physics or science (e.g., Adams et al., 2006; Elby et al., 1997; Halloun, 1996; Halloun & Hestenes, 1998; Hammer, 1994; Muis & Geirus, 2014; Redish et al., 1998). As physics teachers lie in 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 – it is of no surprise that literature commonly includes this area of beliefs when considering one's epistemology. Hence, it is important this area of beliefs be included in the framework exploring teachers' epistemic beliefs about physics knowledge.

Epistemic beliefs about physics knowledge, for this study, entail the beliefs a person holds about the source, content, certainty, and structure of physics knowledge. Table 1 gives a summary of these four areas and their dichotomies.

Table 1. *Summary of the Four Areas of Epistemic Beliefs about Physics Knowledge*

1. Beliefs about the source of physics knowledge can be:
    - Physics knowledge is discovered from a pre-existing and external reality, or
    - Physics knowledge is constructed by humans.

2. Beliefs about the content of physics knowledge can be:
    - Physics knowledge is mathematics-based in formulae, or
    - Physics knowledge is concept-based and qualitative in nature.

3. Beliefs about the certainty of physics knowledge can be:
    - Physics knowledge is absolute and unchanging, or
    - Physics knowledge is tentative and subject to change.

4. Beliefs about the structure of physics knowledge can be:
    - Physics knowledge is a collection of isolated ideas, or
    - Physics knowledge exists as a coherent system of connected ideas.

Method

This study sought to develop a valid and reliable instrument able to measure teachers' epistemic beliefs about physics knowledge. Using the literature-defined theoretical framework describing the four areas of epistemic beliefs about physics knowledge as they contributed to teachers' epistemic beliefs about physics knowledge, a quantitative instrument was developed. 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 the data could be used for an exploratory factor analysis, and this was commonplace in the literature, this researcher moved on to conduct an exploratory factor analysis to see whether an acceptable factor structure might exist.

Survey Development

DeVellis' (2017) eight steps to developing measurement scales were applied in the creation of this instrument. These steps include: (1) determine what you want to measure, (2) generate an item pool, (3) determine the formal for measurement, (4) have items reviewed by experts, (5) consider including validation items, (6) administer items to a development sample, (7) evaluate the items, and (8) optimize scale length. As suggested by DeVellis (2017), theory is important to the conceptualization of constructs in any scale. To determine what was being measured, theory was devised from literature on the four areas contributing to one's epistemic beliefs about physics knowledge, and an item pool generated using the four aforementioned instruments commonly found in existing research about epistemic beliefs about physics (*EBAPS, CLASS, VASS,* and *MPEX).* Statements and categories for each of the four devices were analyzed as to their connection to each of the four areas of beliefs about physics. For example, in the *Maryland Physics Expectation Survey* (Redish et al., 1998), two categories were identified as particularly relevant to the beliefs about the content of physics knowledge: (1) concepts exploring student beliefs on underlying ideas and memorization in physics, and (2) math links exploring student beliefs on the role of mathematics within physics. Relevant statements were organized and considered in the creation of those statements included within the developed instrument.

After identifying and organizing statements, removing redundant statements, and rephrasing any used statements to address the beliefs of teachers' instead of physics learners, statements were compared within each area of belief. Statements were then assigned as aligning with either description of belief about each area. For example, a statement regarding one's beliefs about the structure of physics may be coded as representative of either "physics knowledge is a collection of isolated ideas" (termed "isolated") or "physics knowledge exists in a coherent system of connected ideas" (termed "coherent". Those statements that could not be coded strongly to either statement in each area were disregarded; ideally, the grey area would have been represented by participants' ranging responses on the Likert scale measuring the degree of agreement or disagreement with each item. After this process, the maximum number of statements in any coded section was four; yielding each belief area (source, structure, content, and certainty) a total of 8 statements. The researcher wrote statements for any belief area with less than four statements to develop a total of eight statements for each of area of belief. Finally, statements were compared to criteria identified by DeVellis (2017) for contextual relevance, wording, and purpose and refined as needed.

To meet DeVellis' (2017) third step, the format for measurement was considered. As is common in epistemic beliefs research (e.g., Adams et al., 2006; Elby et al., 1997; Redish et al., 1998; Schommer, 1990, 1993; Qian & Alvermann, 1995), a Likert scale was used within this survey. Likert scales offer a useful way to measure beliefs (DeVellis, 2017). The Likert scale also 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 was used for the creation of numerical, ordinal data. The use of an even number of responses forces a person to agree or disagree with a statement; as teachers are generally unaware of their beliefs about physics (Mulhall & Gunstone, 2008), this type of forced response was used to avoid the use of neutral responses when teachers were unsure about their beliefs. Participants were not forced to complete all items and incomplete data sets were not included in the sample for this study.

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 has statements written to reflecting each of the extreme views potentially reflected in those areas. The instrument employed a four-point Likert scale (4 = Strongly Agree, 3 = Somewhat Agree, 2 = Generally, Do Not Agree, 1 = Do Not Agree). Note, DeVellis' (2017), recommended step 5 is the consideration of validation items; to maintain a manageable length, additional items were not included, but this step instead met by comparing final constructs to a pre-determined theory.

Initial Measures of Validity

As the first measurement for construct validity, and in step 4, DeVellis (2017) recommends having the items reviewed by experts. Face validity of the items and their corresponding subscales was explored by having four experts external to the research consider the instrument. Initial items should be reviewed by experts prior to implementation (DeVellis, 2017). These experts consisted of a physics teacher, physics education researcher, and two science education researchers (with experience developing and validating survey instruments). Experts were provided with a summary of the literature used to develop this survey and asked to consider the (a) individual items for their wording, and (b) groupings of items for their conceptual connections. This resulted in the revision of wording on three items. These items were reviewed again by the experts prior to delivery of the survey and all agreed that the items included were strongly connected to the literature informing each scale.

Participants

This sample consisted of pre-service and in-service science teachers in Western Canada (N = 224; 99 male, 124 female, 1 undisclosed). 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. Of these participants, 14 active physics teachers were also interviewed (as part of a secondary study investigating epistemic beliefs about physics knowledge), whose primary areas of training included chemistry (N = 3), general sciences (N = 3), mathematics (N = 1), and physics (N = 7).

Data Collection Procedures

Survey Collection

The next step in DeVellis' (2017) scale development is to administer the items to a sample of people. Preservice teachers were recruited through science methods courses on campus (given instructor permission) to complete an electronic questionnaire. Preservice teachers were used as they were easily accessed and were developing as teachers of science. Current science teachers were recruited through researcher and collegial contacts as well as social media; this population was more difficult to access since many school divisions in Western Canada require division-specific ethics approval before teachers can participate in educational research. All participants were informed participation was voluntary and they could choose not to answer any questions throughout the survey.

Interviews

As part of a larger study, 14 physics teachers were interviewed regarding their epistemic beliefs about physics knowledge. As is customary in epistemic belief research (e.g., Brownlee & Schraw, 2017; Edwards et al., 2017; Fives & Buehl, 2017; Fuecht, 2017), semi-structured interviews were used in this study. Using epistemic belief literature, general questions were designed to ask participants including "is physics invented or discovered?", "can we know physics without mathematics?", "can ideas in physics change?", and "are the ideas in physics connected to one another?" These questions initiated conversation with the teachers on each of the four areas of epistemic beliefs about physics knowledge and probing questions were used to clarify teachers' explanations. Interviews typically lasted 30 – 45 minutes.

Data Analysis and Results

Factor Analysis

DeVellis' (2017) seventh step is to evaluate the items, find dimensionality, and consider measures of reliability and validity; this step was completed in tandem with his eighth step, optimizing scale length. I chose to follow the analytic procedures modeled by most publications that developed and validated survey instruments investigating epistemic beliefs (see, for example, Cazan, 2012; Hofer, 2000; Lin & Tsai, 2017; Schommer, 1990). Since these methods are consistently used, I proceeded with the (naïve) understanding that these would lead me to a clear, valid, and reliable instrument.

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. The Scree plot, shown in Figure 2, indicated 11 factors that explained more variance than any single variable (eigenvalue > 1); however, one can see that the Scree plot begins to 'level out' at four or more factors, a measure often used to determine the number of factors to extract (DeVellis, 2017). As indicated by the shape of the Scree plot, it was decided that both a four and three-factor solution would be considered.

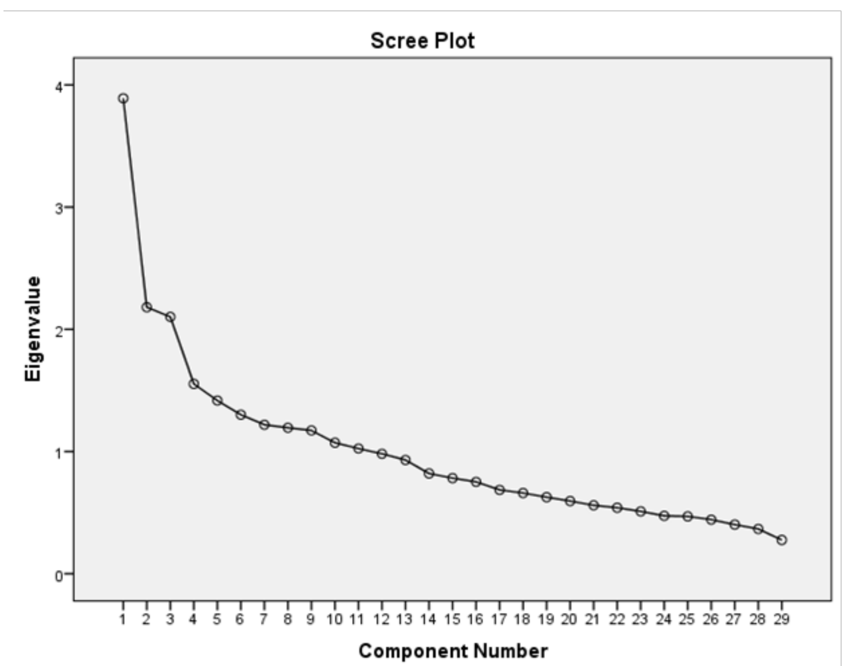

Figure 2. Scree plot of original data.

Factor analysis led to the refinement of the original 29-item instrument. As factor solutions were reviewed, items were considered for deletion if they did not load with any factor (as was observed in many of those aforementioned studies in epistemic beliefs research) or were conceptually inconsistent with the factor on which they were loading (as done by Osborne & Fitzpatrick, 2012 and suggested by Beavers et al., 2013). For example, the statement "different branches of physics are separate and independent of each other" consistently loaded with 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 this statement did not connect conceptually with those statements it was loading. This reduction of statements resulted in the removal of statements originally connected to the subscale *beliefs about physics structure.* Of these eight statements, four failed to load and the other four were conceptually inconsistent with the categories in which they loaded. Once acceptable factor loadings were produced, this was followed by a review of internal consistency as represented by Cronbach alpha coefficients (per DeVellis, 2017).

In both the four and three-factor solutions, shown in Table 2 and Table 3 respectively, areas initially included were reassessed and, in some cases, reconceptualized based on loadings. An expert in science education with knowledge of survey development and validation was consulted and agreed with the naming and descriptions of the reconceptualized factors. Both solutions indicated factors of *beliefs about the certainty,* and *source* of physics knowledge. Additionally, both solutions saw an unexpected factor emerge, called *beliefs about authority;* statements in this factor discussed who had the authority to create and dictate physics knowledge. For example, two statements in the new *beliefs about authority* factor included, "once an idea in physics has been verified and accepted, there is little room for argument on it," and "it is important physics knowledge be understood as it has been derived by physicists." Unique to the four-factor solution was a factor titled the *connection* of physics knowledge; the items in this factor all spoke to the explanation or connection of physics ideas with other aspects. For example, statements such as "one of the most crucial skills in understanding physics is being able to explain why a formula works," connected physics knowledge with mathematical-relationships and statements such as "physics provides us with factual information about the natural world," connected physics knowledge and the natural world. In both the three and four-factor solutions, it was noted that many of those statements thought to represent the area of *belief about the content of physics knowledge* 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 is absolute and held by some external authority.

Upon review of both factor loading structures, it was determined that the three-factor structure was likely a better representation of those constructs being represented. The fourth factor, called *physics connections*, was both weakly correlated (α=0.42 overall and α=0.30 for preservice teachers) and conceptually weak (since items were only loosely connected). The items in this category spoke to a variety of connections such as those between physics and the real world and physics knowledge and mathematics. As *physics connections* 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 4 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 (0.61 for preservice teachers); 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 (40.61% of variance for preservice teachers); when considering the entire sample, 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 2, each item loaded on a single factor and loading values range between 0.45 and 0.72 (0.54 and 0.75 for preservice teachers) 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.

Table 2. *Teachers' Epistemic Beliefs about Physics (TEBaP) Survey Items and Corresponding Actor Loadings (Final 3 Factor Solution)*

	Factor		
Item no.	Beliefs about authority	Beliefs about certainty	Beliefs about source
Q8	0.65 (0.54)		
Q23	0.63 (0.64)		
Q19	0.59 (0.47)		
Q24	0.56 (0.48)		
Q21	0.55 (0.44)		
Q17	0.54 (0.58)		
Q6	0.45 (0.57)		
Q18		0.74 (0.75)	
Q9		0.69 (0.66)	
Q13		0.56 (0.58)	
Q11		0.52 (0.57)	
Q4			0.72 (0.66)
Q5			0.71 (0.66)
Q28			0.64 (0.64)
Explained Variance	17.10% (16.66%)	12.51% (11.97%)	11.77% (11.44%)
Alpha Value	0.66 (0.61)	0.52 (0.56)	0.53 (0.45)
Response Mean	2.56 (2.51)	2.57 (2.58)	3.60 (3.50)
Response SD	0.78 (0.77)	0.87 (0.86)	0.57 (0.62)

Note. Numbers in parentheses are those values produced when only pre-service teacher data was analyzed.

Table 3. *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 (0.59)			
Q23	0.62 (0.54)			
Q8	0.57 (0.62)			
Q7*	0.56 (0.58)			
Q21*	0.55			(-0.50)
Q29	0.53 (0.63)			
Q6	0.52 (0.59)			
Q18		0.68 (0.67)		
Q9		0.66 (0.54)	(0.41)	
Q13		0.66 (0.43)		
Q11		0.54 (0.60)		
Q4			0.75 (0.59)	(-0.52)
Q5			0.69 (0.60)	
Q28			0.62 (0.49)	
Q12*				0.77 (0.68)
Q15*		(-0.51)		0.61
Q24	(0.49)			0.51
Total Explained Variance	14.09% (13.7%)	11.22% (11.30%)	10.79% (10.46%)	9.89% (10.33%)
Cronbach's Alpha	0.68 (0.68)	0.55 (0.38)	0.53 (0.34)	0.42 (0.30)

Note. *Indicates statement removed from 3 Factor Solution due to DNL Numbers in parentheses are those values produced when only preservice teacher data was analyzed.

Table 4. *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 an external authority, including mathematics and scientists.	Mathematics is the source of factual knowledge in physics.
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.

Comparing Interview Data and Survey Data

Interviews were conducted with 14 participants from this sample as part of a secondary, but parallel, study. Interviews were transcribed by the researcher and sent, along with initial epistemic belief profiles and accompanying descriptions of how these areas of beliefs about physics were defined, to each participant to ensure accuracy through member checking. (Guba & Lincoln, 1989). Participants reviewed the researcher interpreted epistemic belief profile (which indicated the area of each of the dichotomies in Table 1 it appeared that the teacher agreed) and had the opportunity to request revision of the researcher's interpretation; no participant requested changes to their epistemic belief profile.

Statements were coded using thematic analysis during which patterns (or themes) viewed within the data were identified, analyzed, and reported (Braun & Clarke, 2006; Maguire & Delahunt, 2017). The thematic analysis involves six phases: (1) familiarize yourself with the data, (2) generate codes (if necessary) and code the data, (3) search for themes, (4) review themes, (5) define and name the themes, and (6) select exemplars representative of the theme and report (Braun & Clarke, 2006). Researchers using thematic analysis are also encouraged to begin writing down initial codes and reflecting on data as early as possible (Braun & Clarke, 2006; Nowell et al., 2017; Maguire & Delahunt, 2017); hence, while interviewing participants, emerging themes were noted as they surfaced.

Initially, statements were coded using the *a priori* framework described in Figure 1. It should be noted that this researcher opted to code interviews using the original four constructs (beliefs about the source, content, certainty and structure of physics knowledge) instead of those constructs in the 3-factor solution (beliefs about the authority, certainty, and source of physics knowledge). The original framework was used because it was strongly connected to the epistemic belief literature, unlike the newly emerged factors; since this qualitative study sought to describe teachers' epistemic beliefs about physics knowledge, it was decided that the literature-informed framework was more likely to produce a theoretically grounded result.

After coding transcripts using the original framework (Figure 1), statements were then sub-coded using the dichotomy of the area of belief which it most aligned (see Table 1). For example, if a statement was initially coded as "beliefs about the certainty" of physics knowledge, it would then be sub-coded as either aligning with the belief that physics knowledge was "tentative and subject to change" or that physics knowledge was "absolute and unchanging." For the duration of analysis, codes were frequently revisited and, when necessary, revised (as recommended by Braun & Clarke, 2006) to ensure consistency. Following coding, the initial, interview-generated and participant-verified epistemic belief profiles were compared to the coded statements for each interviewee. This comparison prompted the alteration of two participants' epistemic profiles. Final epistemic profiles were sent to participants for verification with justification regarding those changes made; no participant requested changes to these epistemic profiles.

Full results of interview-determined epistemic profiles are the subject of another article, but the comparison of these profiles with those produced from the teachers' initial survey results are relevant to the purposes of this piece. The 29-item surveys of these 14 teachers were analyzed using the originally conceived factor-structure, to match the framework used in coding, 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 are shown in Table 5 with an 'X' indicating that the participant's survey results and interview results matched. Taking the interview results to be considered 'correct', as they were verified by the participant, the original survey appears to be problematic in measuring teachers' epistemic beliefs about the content, source, and certainty of physics knowledge as the highest number of participants with matching results in any area was 50% with one exception. Interestingly, the one area of epistemic beliefs about physics knowledge that matched for all teachers' interview and survey profiles was their *beliefs about the structure of physics knowledge*. Yet, all of the 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. This lack of agreement between the two data sources indicate that the instrument likely does not match the factor structure commonly proposed in the literature, supporting the findings from the factor analysis.

Table 5. *Interview Results Compared to Survey Results for Areas of Belief about Physics*

	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

Discussion and Conclusion

An 'Acceptable' Instrument?

The intent of this study was to develop and validate a new questionnaire designed to explore teachers' beliefs about physics. Using similar approaches to those who had designed instruments intended to quantitatively measure epistemic beliefs in science (e.g., Adams et al., 2006; Elby et al., 1997; Redish et al., 1998) and following the instruction of DeVellis (2017), a proposed set of items matching a theoretically grounded framework were designed. Through the commonly used practice of manipulating which items were included in the factors of this instrument (Beavers et al., 2013), an 'acceptable' revised 14-item instrument was produced. Based on the quantitative analysis, this revised instrument could be used with preservice and in-service science teachers to describe their beliefs about authority in, certainty of, and the source of physics knowledge; these subscales reflect those found in other epistemic beliefs research (e.g., Clarebout et al., 2001; Hofer, 2000; Schommer, 1990) but they do not conceptually align with those areas of beliefs about knowledge in physics that have been commonly included in studies investigating epistemic beliefs about physics (or science). For example, results from this factor analysis indicate that this instrument was not equipped to describe teachers' beliefs about either the source or the content of physics knowledge, which are areas commonly included in epistemic beliefs research (Hammer, 1994; Muis & Geirus, 2014; Sin, 2014; Wei & Chen, 2019). In contrast, interview results indicated that this survey may have been (only) appropriately measuring teachers' beliefs about the source of physics knowledge. The results of the KMO-MSA and Bartlett's test of sphericity indicate that the factor analysis of this data was appropriate but considering all of the findings in this study (e.g., variance, reliability measures, correlation with interview profiles, etc.) many issues were identified in using this instrument to measure teachers' epistemic beliefs.

Exploratory factor analysis results revealed that these items had a 3-factor, 14-item solution, accounting for 41.4% of the total variance which is similar to the results found in other epistemic belief research (see Schommer, 1990, 1993; Wood & Kardash, 2002) with epistemic scales having explained variance as low as 15% (Wheeler, 2007) but low in terms of general survey development. As some examples in epistemic belief survey development, Schommer et al. (1992) found a four-factor solution representing a variance of 46%, Clarebout et al. (2001) found Schommer's survey to have a variance of 21% explained by four-factors, and a survey administered by Schraw et al. (2002) showed a five-factor structure representing 35% of the variance. As this study used teachers, the low explained variance might arise from the fact that teachers' have many different backgrounds in science, teaching contexts, and scientific philosophies. Arguably, given these results, this study's instrument with a variance of 41.4% could be considered acceptable for epistemic beliefs research, particularly because beliefs are inherently difficult to define. Yet, according to Beavers et al. (2013) educational researchers have largely agreed that an acceptable exploratory factor solution should account for 75 – 90% of the variance with few studies indicating as little as 50% being acceptable. Given this claim, 41.4% of explained variance is not likely enough to claim a valid and reliable instrument.

The largest contributor to the explained variance of this instrument was the factor titled *beliefs about authority* (41.3% of total variance explained). This strong factor of beliefs about authority also parallels findings from other researchers investigating epistemic beliefs (e.g., Wheeler, 2007; Elliott & Chan, 1998), but contradicts others where authority is a relatively less cohesive factor (e.g., Jheng et al., 1993; Schommer, 1993). Differences between those studies and the results from this instrument are to be expected as those studies investigated students' epistemic beliefs and this study explored teachers' epistemic beliefs. Teachers' beliefs about authority in sciences are likely more varied than those beliefs held by students since teachers have had more time and life experience to explore scientific philosophy and beliefs. Presumably, teachers have also shifted from believing that knowledge comes solely from some authority to being a part of the authority structure in education, potentially altering the way they view authority in physics. To further explore the large unexplained variances in teachers' epistemic beliefs about physics knowledge, it is suggested that future research investigate the cohesiveness of teachers' epistemic beliefs specific to their scientific and educational training as well as other demographic variables.

Exploratory factor analysis revealed some consistency of items within their respective factors, with Cronbach's alpha values ranging between 0.53 and 0.66 in the three-factor solution. In epistemic belief literature, a minimum value of Cronbach's alpha above 0.70 has been claimed as 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 (e.g., Chan & Elliott, 2002; Clarebout et al., 2001; Hofer & Pintrich, 1997; Wheeler, 2007). In creating the *Epistemological Questionnaire*, arguably the most cited quantitative instrument in the field of epistemic beliefs, Schommer (1990) reported internal consistency of her factors to range between 0.10 and 0.79 with most between 0.50 and 0.60 (similar to values found in this study). In a recent review of science education articles that used Cronbach's alpha, Taber (2018) found that some studies in science education claimed that alpha values as low as 0.45 could be considered sufficient. However, Taber also cautions authors to consider these values alongside other statistical measures (such as factor loadings). Given the expectation of $\alpha \geq 0.70$ from epistemic beliefs literature, that the produced factors did not align conceptually with this literature, and the low explained variance for the solution, it would appear that the individual scales, at least with this population, were not internally consistent. This finding, along with consistent results in the epistemic beliefs literature, suggests that those researchers attempting to develop epistemic belief profiles using quantitative instruments complete some type of factor analysis with their results before claiming to produce accurate profiles.

An interesting outcome of the exploratory factor analysis was the collapsing of the subscales anticipated to represent *beliefs about the content of* and *authority in* physics knowledge. Literature suggests that consideration of whether physics is based in mathematics and formulae or qualitative explanations (often called conceptual physics) is a distinct area of belief in physics; for example, both Elby (2011) and Hammer (1994) separate these from beliefs about learning physics (by authority or independently). Efforts to analyze these areas (content and authority) of belief separately are also present in epistemic cognition literature (e.g., Yavuz, 2014). Yet, very few studies have conducted factor analysis on any quantitative instrument attempting to represent these beliefs. Assuming this factor analysis did provide an appropriate three-factor model of the refined (14-item) survey, this study shows that teachers' *beliefs about the content of physics knowledge* may not be a separate area of belief, but, in fact, speak to *beliefs about authority in physics knowledge*. Many items about mathematics as a primary contributor in physics loaded with those statements indicating physics came from an authority, such as scientists, outside of the knower. This suggests that science teachers may see mathematics as an external authority that creates knowledge in physics. Given this finding, this researcher recommends that future studies investigate connections between teachers' beliefs about the role of mathematics and its' connection to authority in physics knowledge.

A Word of Caution

This study attempted to develop and validate a new instrument intended to measure teachers' epistemic beliefs about physics knowledge but found that measuring epistemic beliefs quantitatively was not as straightforward as the literature made it seem. A three-factor solution was produced through exploratory factor analysis but given such a significant change to the original 29-item instrument, among other confounding factors, the acceptability of this solution as accurate is questionable. 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). Considering teachers' interview-coded epistemic belief profiles alongside their survey-measured epistemic belief profiles produced in this study, only the proposed factor describing *beliefs about the structure of physics knowledge* measured what was intended (as this is the only area with more than 50% of teachers agreeing). However, this was the only proposed factor that did not present itself in either the three or four-factor solutions. It is with these disagreements between interviews and survey, combined with the low Cronbach alpha values, and the finding that the most acceptable, three-factor, solution in this study only accounted for 41.4% of the variance in results that this research supports the claims of scholars such as Elby, Adibelli, and Bailey in questioning whether surveys indeed can accurately measure epistemic beliefs.

As one specific problem to consider, since beliefs are all loosely connected, especially in epistemic beliefs research (Hofer, 2000; Schommer, 1990, 1994), it would seem antithetical to attempt to clearly separate factors in any analysis of beliefs. As Hilpert and Marchand (2018) explain, educational psychology often reduces complex problems to models that inadequately describe the phenomenon; to this researcher, this is particularly prevalent when conducting quantitative research. Attempting to separate teachers' epistemic beliefs about physics knowledge into 'neat' and discrete factors ignores the complexity of this system. Complex systems cannot be studied by considering only their components (Hilpert & Marchand, 2018; Holland, 2006). Teachers' epistemic beliefs about physics knowledge are indeed complex, as implied by the interdependent nature of the framework proposed in this study (Figure 1), therefore it may not be appropriate to use a reductionist methodology such as factor analysis when studying teachers' epistemic beliefs about knowledge. If this is the case, it may be that using quantitative surveys that are validated using traditional methods (i.e., use factor analysis, Cronbach's alpha, etc.) ignores the complex nature of researching teachers' epistemic beliefs about physics knowledge. Yet, despite this significant problem, it is still common to use quantitative instruments in epistemic beliefs research in education

Perhaps, given the messy nature of beliefs (Pajares, 1992), a subtler approach, such as qualitative research, is needed when investigating these slippery constructs. Given the findings of this study, I caution researchers to strongly consider whether their results of factor analysis truly show the validity of instruments investigating beliefs; do quantitatively determined profiles truly represent one's epistemic beliefs? According to those teachers interviewed in this survey, it is not always the case (particularly with this instrument) that a quantitatively measured profile accurately represents a teachers' epistemic beliefs about physics knowledge. Admittedly, using qualitative methods forces researchers to use smaller sample sizes than would be achievable with surveys, but this researcher was certainly more confident in those epistemic belief profiles determined through interviews than those measured from the quantitative instrument. If this is the case, it may be that researchers of epistemic beliefs should turn their focus to (or at least incorporate) qualitative data to accurately capture the dimensions of teachers' epistemic beliefs about physics knowledge.

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