Using continua to analyze qualitative data investigating epistemic beliefs about physics knowledge: Visualizing beliefs

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[This paper is part of the Focused Collection on Qualitative Methods in PER: A Critical Examination.] Epistemic beliefs about physics are most often investigated using quantitative instruments that reflect binary conceptualizations of those beliefs. This study reports from a qualitative study which used continua to represent the epistemic beliefs about physics knowledge of sixteen Western Canadian, high school physics teachers. Unlike other research, this study did not intend to compare epistemic beliefs to any specific epistemology of science. This article presents a novel, more nuanced means of analyzing interview data to construct profiles to describe epistemic beliefs. The epistemic belief profiles of the physics teachers in this study reflect each of four areas of a literature-derived theoretical framework regarding epistemic beliefs about physics knowledge. These four areas are individuals' beliefs about the (a) source, (b) content, (c) certainty, and (d) structure of physics knowledge. The use of thematic analysis research methods and reasons for the placement of participants along continua are discussed. Potential classroom applications of this research include prompting discussions about student epistemic beliefs and collecting more nuanced representations of students' epistemic beliefs to inform teaching.

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I. USING CONTINUA TO ANALYZE QUALITATIVE DATA INVESTIGATING EPISTEMIC BELIEFS ABOUT PHYSICS KNOWLEDGE: VISUALIZING BELIEFS

Physics education researchers have been interested in epistemic beliefs research for the past three decades. Research conducted in the 1990s, such as that of Hammer [1] and Roth and Roychoudhury [2], paved the way for theorizing about the conceptualization of individuals' epistemic beliefs about physics. Researching epistemic beliefs about physics was of such interest to physics education researchers that Elby [3] published a chapter describing how to begin researching epistemic beliefs. Epistemic beliefs research in physics education research (PER) continues to grow, as evidenced by the journal Phys. Rev. Phys. Educ. Res. continuing to share works investigating epistemic beliefs (e.g., [4–6]).

Epistemology is a philosophical area focused on explaining what constitutes knowledge [7]. Epistemology lacks a single definition [8–10], but researchers working in the field of epistemology are typically interested in the source of, the certainty of, and the organization of knowledge [11,12]. Epistemic beliefs[1] describe an individual's conception of knowledge [13] and, to us, epistemic beliefs are constructed by individuals as a consequence of their experiences.

Research investigating epistemic beliefs has a rich history in science (and physics) education and continues to receive increasing attention in this field. For example, Lee *et al.* [14] found 225 studies eligible for their systematic literature review of methodologies used to measure epistemic beliefs and epistemologies about science published between 2010 and 2019. Epistemic beliefs about science continue to be studied and related to various educational constructs such as, for example, teacher education [15,16], teaching practices [17–19], and learning [20,21].

Historically, quantitative surveys have been used to investigate epistemic beliefs about science held by individuals and groups [4,14,22–24]. Whether, and the extent to which, quantitative instruments accurately represent epistemic beliefs has been called into question [25,26]. As Elby [3] claimed, surveys are the most common tools used to investigate epistemic beliefs in PER but qualitative methods, namely, interviews, are "the backbone of

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[1]In this study, the term epistemic beliefs is used but it is acknowledged that others may use the term personal epistemology to describe this concept.

epistemology research" (p. 18). Interview data affords a richer description of epistemic beliefs and enables researchers to capture the nuances required for in-depth research into and reporting of epistemic beliefs [14,26]. Despite the prevalence of survey-based research in PER about epistemic beliefs, interviews offer a subtlety that is difficult to capture using quantitative methods.

Quantitative methods (i.e., using Likert-scale surveys) in epistemic beliefs research make it easy to represent individual and group profiles using a numeric scale. However, qualitative methods investigating epistemic beliefs have not traditionally taken this approach. Interview data exploring epistemic beliefs about science are often presented as individual cases with rich descriptions, and then common themes, identified for the reader [1,14,27,28]. Such means of presentation provide detailed descriptions of individuals' epistemic beliefs and the contexts of those beliefs. Yet, these rich descriptions can make it difficult to consider the epistemic profiles of a group of individuals.

Unlike most quantitative research into epistemic beliefs, this study did not intend to assess teachers' understanding of any accepted model of epistemology. Instead, we aimed to develop a method that could describe teachers' beliefs about physics knowledge at a particular moment in time. Having a means of describing the epistemic beliefs about physics of a group of individuals, such as teachers or students could be valuable for researchers and instructors alike. For example, researchers can begin to analyze the epistemic beliefs of their individual participants with the nuance afforded by individual interviews and still analyze the beliefs of a group of participants. For instructors, knowing the epistemic beliefs profiles of individual students is helpful but time consuming to synthesize using qualitative methods; having a way to represent these individual students and describe their beliefs profiles as a class can help the instructor make decisions about teaching. Hence, ways to interpret and visualize qualitative PER investigating epistemic beliefs are worth exploring. This article presents a means of produce visual representations of profiles for representing and comparing individuals' epistemic beliefs about physics knowledge from qualitative datasets.

II. EPISTEMIC BELIEFS: AN OVERVIEW

There is some debate among scholars about whether epistemic beliefs can be considered domain-specific (i.e., connected to a specific area of knowing or topic) or generalizable across topics (i.e., similar across areas of knowing) [8,29]. There is evidence to suggest that epistemic beliefs can be considered domain specific. For example, studies have found that individuals held differing epistemic beliefs when asked to consider knowing in different subjects such as math, science, and history [30,31]. Considering this evidence and the scores of researchers investigating epistemic beliefs about science [14], we subscribe to the position that epistemic beliefs are domain-specific, further supported by Fives and Buehl [8] and Hofer [32,33]. To us, epistemic beliefs about physics knowledge are a specific construct and may diverge from those beliefs about knowing in other subject areas.

Epistemic beliefs have been part of the educational research conversation since Perry [33] studied their development. For approximately 20 years, studies were concerned with describing the development of individuals' epistemic beliefs as unidimensional constructs [34,35]. However, in the 1990s, with the work of Schommer [12,36,37], researchers began investigating epistemic beliefs as multi-dimensional constructs. This multidimensional approach remains the most prevalent way of describing epistemic beliefs, particularly in education. We concur with researchers, such as Fives and Buehl [8], Hofer and Bendixen [11], and Schiefer *et al.* [38], who indicate that individuals' epistemic beliefs can be interpreted using a multidimensional approach where the beliefs are related but work independently from each other. This means that beliefs in one dimension cannot be predicted by the beliefs espoused in another dimension. Multidimensional models continue to inform research on epistemic beliefs about science education [14]. This approach to epistemic beliefs is integral to our work and fully described in our theoretical framework.

Whether epistemic beliefs about knowing can be separated from beliefs about learning has also been hotly debated in epistemic beliefs research. We assumed that epistemic beliefs about physics knowledge could be studied without focusing on beliefs about learning physics knowledge, as has been done by other researchers of epistemic beliefs [7,17,20]. However, we do recognize that beliefs about teaching and learning as well as epistemic beliefs about knowledge all contribute to one's epistemological worldview as defined by Olafson and Schraw [39]. This study is predicated on the view that epistemic beliefs about physics knowledge were separable from beliefs about learning physics. Accordingly, these areas are not represented in our conceptualization of epistemic beliefs about physics.

It should be noted that we focus our research on epistemic beliefs about science—specifically physics—instead of the nature of science (NOS). Researchers have described the NOS as the epistemology of science [40]; there are parallels between the NOS and epistemic beliefs, and the two concepts are undeniably connected. Supported by Ozgelen [41], we conceptualize epistemic beliefs as one important factor that facilitates (or hinders) an understanding of the NOS. In those studies, considering the nature of science, there is a focus on determining understandings[2] of an existing epistemology, defined as the NOS (for example,

[2]Understanding is used to portray the approach to exploring conceptions of the NOS, but authors have also commonly used the terms perceptions, perspectives, and views in the NOS literature.

see [42–46]). Our study was not focused on whether individuals espoused an acceptable understanding (i.e., about the NOS), rather, we sought to represent individuals' beliefs about physics knowledge. The inclusion and comparison of teachers' views to different, accepted understandings of the nature of physics (or NOS) could present interesting findings in a future study but are not the intended focus of this work.

A. Researching epistemic beliefs

Epistemic beliefs about science and physics knowledge are commonly researched using quantitative approaches [3,14]. Schommer's [37] study was also among the first to quantify epistemic beliefs. Schommer developed a 63-item questionnaire to identify individuals as either presenting a naïve belief or a sophisticated belief in each of four areas: Innate ability, simple knowledge, quick learning, and certain knowledge.[3] This multidimensional structure, with epistemic beliefs being described as naïve or sophisticated, continues to permeate the most popular epistemic beliefs surveys used across domains, such as the *Epistemological Questionnaire* [37], and also those surveys used to describe epistemic beliefs about physical sciences including the *Epistemological Beliefs Assessment for Physical Sciences (EBAPS)* [47], the *Colorado Learning Attitudes about Science Survey (CLASS)* [48], the *Views about Science and Physics Achievement Survey (VASS)* [49] and the *Maryland Physics Expectations Survey (MPEX)* [24]. Of the 225 studies identified by Lee *et al.* [14] in their review of methodologies used to measure epistemic beliefs about science, over 60% of those studies relied solely on quantitative measures. Quantitative approaches are the most common approach to investigating epistemic beliefs about science.

B. Questioning quantification

Commonly, instruments aimed at measuring epistemic beliefs develop belief profiles using multiple scales. For example, the *Epistemological Beliefs Assessment for Physical Sciences* (EBAPS) developed by Elby *et al.* [47] measures epistemic beliefs along five different axes (or areas): structure of scientific knowledge, nature of knowing and learning, real-life applicability, evolving knowledge, and source of the ability to learn. Based on their responses to the survey, individuals are assigned a number 0–4 for each of the five areas. Researchers can determine the individual's profile by referencing the numbers in each area. For example, a score of 4.0 on the scale "structure of scientific knowledge" indicates that the participant believes that science knowledge is coherent, conceptual, and highly structured. A score of 3 might mean that they believe science knowledge is generally coherent, conceptual, and structured but their responses overall indicate that they do not consistently respond to statements in this scale.

Quantitative researchers combine these numeric values from individuals to determine the belief profile of a group. For example, Johnson and Willoughby [4] report the epistemic belief profiles of students in various courses using the numeric mean in various dimensions (such as the structure of scientific knowledge, evolving knowledge, and the ability to learn in science) as a representation of student beliefs in a course. These profiles are commonly represented by reporting the mean and standard deviation of a group score on the Likert scale.

Quantitative surveys often using Likert scales are widely used in epistemic beliefs research [3,14]. Unfortunately, surveys in epistemic beliefs research often fail to meet traditional standards for survey validation. For example, Schommer's [37] questionnaire is the most widely used survey in epistemic beliefs research but has been criticized for its ambiguous wording, lacking a replicable factor structure, and having low internal consistency [50–52]. According to Lee *et al.* [14], only about half of research articles publishing results of quantitative surveys measuring epistemic beliefs provide values of reliability and validity.

Those studies that do report values of reliability and validity often fail to meet minimum standards. For example, epistemic beliefs surveys have often been deemed acceptable with explained variance as low as 15% [36,50,53]. This is very low in terms of general survey development where the goal of this type of analysis should be to explain as much observed variance as possible [54]. One would expect an acceptable solution to explain at least 75%–90% of the variance [55]. Similarly, epistemic beliefs surveys are often considered reliable with low values of internal consistency. For internal consistency, epistemic beliefs researchers have described a minimum value of Cronbach's alpha as 0.70 to be acceptable [22,56,57]. Yet, epistemic beliefs surveys rarely meet this expected measure and are still deemed reliable [50,52,58]. As one example, Schommer's [37] survey was considered acceptable with Cronbach alpha values ranging between 0.10 and 0.79 (most were between 0.50 and 0.60). Despite epistemic belief surveys often failing to meet the minimum expectations for reliable and valid survey development, researchers of epistemic beliefs continue to use these surveys to describe epistemic beliefs and produce individuals' epistemic belief profiles.

According to Elby [3], traditional survey validation methods may not be optimal for epistemic belief research as surveys lack the subtlety necessary for these inquiries. Further, Watson [26] notes that her attempted survey to measure teachers' epistemic beliefs about physics failed traditional robust validation methods and validation when compared to interview analysis. It may be that Likert scales—which are most used on epistemic beliefs

[3]Schommer (1990) included beliefs about learning into an individual's epistemic beliefs.

quantitative scales—rarely adequately measure epistemic beliefs [25]. Yet, even those surveys which do not use Likert scales (e.g., *VASS*) have analysis problems, such as the assumption that teachers approach science as experts when research has shown that physics teachers are often unaware of the philosophy and nature of physics [59,60]. Given the issues with survey-based approaches to epistemic beliefs research, we support the use of qualitative and descriptive approaches in epistemic beliefs research within physics education.

C. Using continua to represent epistemic beliefs about physics knowledge

Epistemic beliefs research has been criticized for representing beliefs as binaries [61–63]. Historically, multidimensional representations of epistemic beliefs have used binaries to describe individuals' beliefs in various areas. For example, using quantitative surveys, Schommer [12,37] and Hofer [64] labeled students' epistemic beliefs as either naïve or sophisticated in each of five belief areas. In his qualitative research with physics students, Hammer [1] does not use the words naïve or sophisticated, but his work reflects the binary approach of Schommer and Hofer. We contend that the representation of epistemic beliefs as binaries neglects the nuance required in beliefs research. Our view is supported by the calls of Sinatra [63] and Murphy and Alexander [62] for researchers to move from binary representations of epistemic beliefs to those that represent a more fine-grained understanding of these beliefs. As such, representations of epistemic beliefs must evolve to include the subtlety necessary when describing such beliefs.

Profile development is common in quantitative epistemic beliefs research but not a common representation in qualitative research that investigates epistemic beliefs about physics. Instead, qualitative research often uses thick, written descriptions to detail these beliefs. In this study, we developed continua to reflect the nuance that we considered necessary for the analysis of epistemic belief and, at the same time, still provide epistemic belief profile descriptions. These continua were and can be used to visualize a group of individuals' epistemic beliefs about physics in a succinct format.

In this study, an individual's epistemic beliefs about physics knowledge were represented between two extremes in each of the four areas of beliefs. These two extremes were typically from the binary representations found in the literature. This research contributes to the growth of epistemic beliefs research by offering an approach to visualize qualitative research investigating epistemic beliefs which more appropriately captures the nuance inherent in beliefs than those methods using only binary labels.

The intention of this research was to describe epistemic beliefs about physics knowledge, not to compare individuals' epistemic beliefs to any specific epistemology. We recognize that different fields of physics, and different schools of epistemology, may be represented at different points along each of the continua. It would be impracticable to pinpoint where each subdiscipline of physics lies, especially since physicists and philosophers would likely debate these conceptions depending on their views of the nature of physics. Further, there are longstanding debates about the philosophy of science and the epistemology described in this philosophy (see [65] for a good overview of these debates). Our aim is not to define the nature of physics but rather to provide a method of meaningfully representing individuals' beliefs about these areas of knowing in physics when using qualitative research approaches.

III. EPISTEMIC BELIEFS ABOUT PHYSICS KNOWLEDGE: A THEORETICAL FRAMEWORK

Discipline-specific studies investigating epistemic beliefs in sciences commonly concern themselves with areas frequently used in epistemic beliefs research including beliefs about the source, certainty, and organization of knowledge [12,29,64,66], as well as adding content-specific knowledge, such as the use of mathematics in physical sciences [24,48,49]. This study draws on literature from the fields of science education and educational psychology and defines epistemic beliefs about physics knowledge as conceived across four areas: epistemic beliefs about the (i) source, (ii) content, (iii) certainty, and (iv) structure of physics knowledge. These four areas constitute a multidimensional system of beliefs where the dimensions are loosely connected—meaning they may influence each other but we have not yet explored this connection—but independent of each other, as represented in Fig. 1.

A. Epistemic beliefs about the source of physics knowledge

Studies [24,47,48,67,68] investigating epistemic beliefs about physics often explore beliefs about whether physics knowledge is invented or discovered. For some, physics knowledge can be conceived as predetermined ideas and structures that have been discovered by physicists [69]. For others, physics knowledge is invented, rooted in experience, and designed by humans [70–74]. Further, it could be that an individual believes that physics knowledge comes from pre-determined ideas, which are then explained by humans or that physics knowledge is designed by humans but based on predetermined structures. The extent to which an individual espouses these beliefs also varies. Unlike the binary representation of believing that physics knowledge is either invented or discovered, in this theoretical framework, 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.

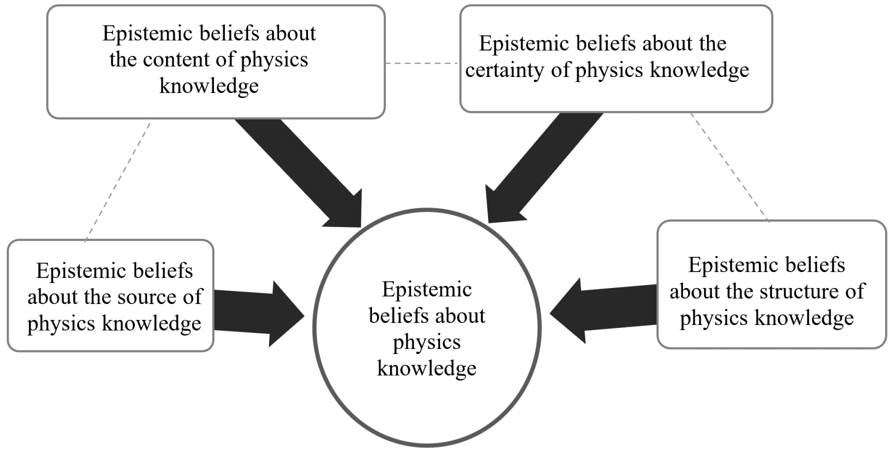

FIG. 1. Depicting the epistemic beliefs about physics knowledge.

B. Epistemic beliefs about the content of physics knowledge

According to Pospiech [75], the substantial application of mathematics to explaining natural phenomena differentiates physics from other sciences. Scholars [73,76–80] have represented physics knowledge as focusing on either a mathematical understanding—emphasizing the use of formulas—or on a conceptual understanding—emphasizing qualitative explanation based on an understanding of physical principles and/or intuition. In his research with first-year physics students, David Hammer [1] described content in physics as either formula centred—stemming from facts, formulas, and procedures—or concept cenetred, based on intuition and logic. This binary encapsulation of epistemic beliefs about content in physics places formulas on one end of knowing and conceptual physics, employing intuition and qualitative explanations based on physical understandings, at the other [61].

The discipline of physics blends intuitive physics with mathematics [75,81], and to conceptualize the two (quantitative and qualitative physics) as separate would be a misrepresentation. We acknowledge this integration and see it as further reason to use continua to represent epistemic beliefs about physics knowledge instead of binary representations. In this study, epistemic beliefs about the content of physics knowledge were conceptualized as represented between a mathematically based understanding—quantitative and formulas centered—and a conceptual—or qualitative—understanding of physics. Some examples of how these beliefs might vary across this continuum (from mathematics to conceptual) include the belief that physics knowledge came from mathematics, that physics knowledge was based in mathematics but used a conceptual understanding to explain the mathematics, that conceptual understanding was the primary way of knowing in physics but supported by mathematics, or that one could understand physics without using mathematics.

C. Epistemic beliefs about the certainty of physics knowledge

Scholars commonly represent epistemic beliefs about the certainty of physics knowledge as perceiving physics knowledge to be tentative and refutable or as absolute and unchanging [47,49,67,68,82]. Science teachers commonly believe that physics knowledge is tentative, but often teach science as unchanging in their approach [70,73]. Whether physics knowledge is refutable or constant was not a focus of this study; this area of belief about the certainty of physics knowledge was used to describe to what degree participants conceived of physics knowledge as unchanging or tentative or as something in between these two binary extremes.

D. Epistemic beliefs about the structure of physics knowledge

In this study, beliefs about the structure of physics knowledge were conceived as existing along a continuum between two extremes: (a) that physics knowledge consists of individual, isolated information or (b) that physics knowledge is a coherent system of ideas. This is another area investigated in epistemic beliefs research in education [7,20]. Specifically, these two contrasting belief extremes are commonly investigated within those studies investigating epistemic beliefs about physics or science [1,24,47–49,67]. Yet, it may also be that individuals express that physics knowledge cannot entirely be connected but that it is a coherent system, for the most part, or that some physics topics can be connected but not other topics, or that some topics are more easily connected than other topics in physics.

E. Summary: Epistemic beliefs about physics knowledge

We describe epistemic beliefs about physics knowledge using four continua focused on individuals' beliefs about the (a) source, (b) content, (c) certainty, and (d) structure of physics knowledge. Beliefs about the source of physics knowledge are represented between physics knowledge being discovered from a preexisting and external reality, and physics knowledge being invented and constructed by humans. Beliefs about the content of physics knowledge are represented between physics knowledge being mathematics based in formulas, and physics knowledge being concept-based and qualitative. Beliefs about the certainty of physics knowledge are represented between physics knowledge being absolute and unchanging, and physics knowledge being tentative and subject to change. Beliefs about the structure of physics knowledge are represented between physics knowledge being a collection of isolated ideas, and physics knowledge being a coherent system of connected ideas.

In applying this continua-based framework to analyzing qualitative data, we propose that the issues identified within epistemic beliefs research might be mitigated. Quantitative approaches are by far the most frequent way of investigating epistemic beliefs about science [3,14] and offer an easy way to visualize belief profiles for individuals and groups. However, as discussed, quantitative research investigating epistemic beliefs has been criticized. The use of continua to represent qualitative data investigating epistemic beliefs about physics knowledge provides the field with an alternative means of encapsulating epistemic belief profiles without relying on quantitative surveys.

Qualitative research in epistemic beliefs about physics knowledge historically presents epistemic beliefs using narratives and representative quotations to describe individuals' or groups' beliefs (see [1,83]). However, these text-heavy descriptions make it difficult to connect epistemic beliefs to other constructs and compare epistemic profiles across time, groups, or studies. Continua synthesize individual profiles and allow for collation, visualization, and collection of the beliefs of a group of participants. Further, the use of continua addresses the prior concerns of epistemic beliefs researchers (e.g., [3,26,63]) by moving from a binary representation of beliefs to one that showcases the necessary nuance of epistemic beliefs research. Finally, using continua to represent qualitative results also gives a pictorial method to member check researcher interpretations with participants. For example, does a participant place themselves near the same location on a continuum as the researcher would? Using continua allows researchers to visualize and member-check nuanced representations of individuals' epistemic beliefs about physics, to collate the epistemic beliefs of a group more easily, and to compare epistemic beliefs about science to other educational constructs.

IV. METHODS

To illustrate our approach, we present one example study with which this approach was used to analyze qualitative data. Sixteen high school physics teachers from across a Western Canadian province participated in semi-structured interviews. Teachers came from both urban ($N = 9$) and rural settings ($N = 7$). Both female ($N = 5$) and male ($N = 11$) teachers were represented, and teachers' experience ranged from 6 to over 20 years. In this province, as it is across North America, it is common to have out-of-field physics teachers, that is, teachers who are not trained as physics teachers or have little if any physics training. As such, participants were not directly asked about their background training in physics to help all physics teachers feel comfortable discussing their beliefs, even if they felt underprepared to teach the subject.

Semi-structured interviews were used, as is common in science education research investigating epistemic beliefs [3,14]. Interviews occurred in person and online. Participants were asked questions about their epistemic beliefs about each area and further probed so that the researchers could appropriately confirm their interpretations. Examples of questions included, "is physics invented or discovered?", "can someone know physics without knowing mathematics?", and "do ideas in physics change?" Interviews typically lasted 30–45 min and were transcribed by a researcher. Pseudonyms are used throughout this article when referring to participants.

A. Thematic analysis

Interview transcripts were coded using thematic analysis during which patterns (or themes) viewed within the data were identified, analyzed, and reported [84,85]. The thematic analysis involved six phases: (i) familiarization with data, (ii) coding the data, (iii) searching for themes, (iv) reviewing themes, (v) defining and naming the themes, and (vi) selecting exemplars representative of the theme and report [84]. Researchers using thematic analysis are also encouraged to begin writing down initial codes and reflecting on data as early as possible [84–86]; hence, while interviewing participants, emerging themes were noted as they surfaced.

Interview transcripts were coded using the theoretical framework previously described and summarized in Fig. 1. After coding the transcripts using the overarching framework, the coded conversations were revisited and recoded to describe where the teacher's beliefs were best represented along each continuum of epistemic belief about physics knowledge. For example, if a statement was initially coded as "beliefs about the certainty" of physics knowledge, it would then be subcoded as aligning with the belief that physics knowledge was "tentative and subject to change" or as representing that physics knowledge was "absolute and unchanging," or as the participant being neutral. Specific placements were determined by themes and the alignment of teachers' statements and overall discussion with each extreme. Using an iterative process, researchers conferred via face to face and remote dialogue and eventually agreed on codes, themes, and participant placement on continua. For the duration of the analysis, codes were frequently revisited and, when necessary, revised (as recommended by Braun and Clarke [84]) to ensure consistency.

B. Rigor and quality in qualitative research

To address the inadequacy of positivist criteria of validity when used in qualitative research, Guba and Lincoln [87] provide what they call "trustworthiness criteria" (p. 233). Nowell *et al.* [86] further explain that these trustworthiness criteria are useful to any qualitative researcher seeking to ensure the acceptability and usefulness of their research. The criteria of credibility, transferability, dependability, and conformability parallel the positivist criteria of reliability and validity. In this study, the trustworthiness criteria were applied to ensure the rigor and quality of this research.

A major criticism of qualitative research is that it does not operate on a single reality or truth, making it difficult to apply the concept of validity. The trustworthiness criteria of credibility reflect the characteristics of internal validity or how well a study measures what it was intended to measure [87,88]. As a measure of credibility, this study used member checking to ensure that participants' intentions were accurately represented. To member check, following each phase of coding, participants were asked to verify whether their beliefs had been accurately interpreted. 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 their verification with justification regarding those changes made. No participant requested changes to their finalized epistemic profiles. We also sought credibility by using persistent observation and data triangulation [89] by seeking saturation in themes through sustained engagement (per [86]).

Further, this study met transferability, dependability, and confirmability. Roughly related to external validity, transferability deals with the issue of generalizing results from any qualitative study [87]. This study met transferability by providing a thick description of the research context, avoiding generalization of findings, and, as described by Sloane [90] providing visual display of information to showcase the researchers' thinking. In the discussion section, we also provide continua which may be transferred to inform the work of other researchers of epistemic beliefs about physics. To increase dependability, researchers must be transparent regarding the research process and show a logical, traceable, and clearly documented research process [86,87,91]. One measure to achieve this was a record of research decisions made maintained and this information was used to write the data collection and analysis sections above. Finally, parallel to objectivity, confirmability addresses how well results represent the context and participants in a study. To achieve confirmability, as suggested by Guba and Lincoln, we thoroughly discuss the reasons behind our data interpretations (to showcase interpretation logic) in the analysis section of this study.

C. Continua development

Data display is an important consideration during any analysis and reporting. Unfortunately, despite our society using more visual forms of communication and a high frequency of displaying data visually in quantitative research, qualitative research has historically underused the visual representation of data [92,93]. However, there are benefits to representing qualitative data using visual representations [90,94]. For example, using visual representations in the presentation and analysis of qualitative data can provide readers with insight into the author's interpretations and thoughts [95]. Visual representations also allow researchers to view patterns across qualitative data sets. In this research, continua were used to represent individuals' epistemic beliefs about physics knowledge so that the profiles of individuals and the group could be efficiently interpreted.

After coding participants' interview data, themes under each continuum were reviewed. Themes, in this study, were sentiments expressed by multiple participants sharing common epistemic beliefs about an area of physics knowledge. For example, when considering the source of physics knowledge, it was common for participants believing that physics knowledge was discovered from external reality to discuss discovering how the world works. Participant placements along each continuum shifted throughout the research as descriptions along the continua synthesized based on participant responses. Coded statements for all participants communicating epistemic beliefs at various points across the continua of each of the areas of beliefs about physics were reviewed and compared to establish consistency and comparability.

V. ANALYSIS

In this section, we describe our rationale for the placement of our participants along each of the four continua of epistemic beliefs about physics. We conceptualize epistemic beliefs about physics as existing along several continua and represent these beliefs between each of the two extremes on each continuum. However, given our finite dataset, we placed the participants in a finite number of groups along the continua. By conceptualizing beliefs as existing along continua we are, and will remain, open to finding more nuance in further studies.

We recognize that these findings represent the outcome of one study. We intend to continue this work and further refine these continua and their descriptions. However, we are confident in our representations since all results were member-checked by individuals throughout the study.

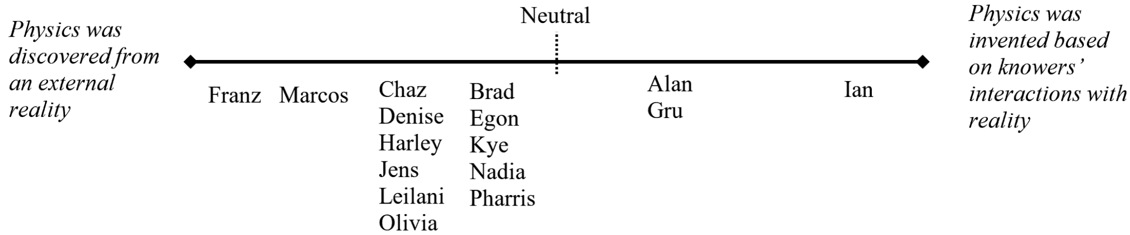

FIG. 2. Continuum of epistemic beliefs about the source of physics knowledge with participants placed.

A. Epistemic beliefs about the source of physics knowledge

Most (13 of 16) participants were placed along the continuum of epistemic beliefs about the source of physics knowledge as believing that physics knowledge was predetermined and waiting to be discovered. These participants were placed along the left side of the continuum represented in Fig. 2. Franz was placed further on the extreme than Marcos since Marcos used some hesitant language (e.g., "it seems like,") whereas Franz did not. These two participants strongly represented the epistemic belief that physics knowledge was discovered.

Participants placed slightly to the left of neutral on this continuum reported sentiments that physics knowledge was discovered from external reality, but they also considered physics knowledge to have been explained by people, i.e., physicists. For example, Pharris explained that "we discovered many things that always existed, but we are also inventing it as we go." Those participants grouped on the less extreme side of believing that physics knowledge was discovered argued that physics knowledge was derived predominantly from external reality, but they also discussed physics knowledge as being invented by humanity.

On the other side of this continuum, three of 16 participants reported the belief that physics knowledge was invented. Egon said, "we have all these laws and rules that we've made to make sense of the things that we've encountered and they're there from the confines of our culture, our understanding of it, and our understanding of the universe." Ian was represented nearer to the extreme end of this continuum than the other two participants because both Egon and Gru described this human-constructed knowledge as based on a shared sense of (external) reality. These three participants described physics knowledge as the explanation of the physical world; in contrast, those participants who believed that physics knowledge was discovered tended to describe physics as the behavior of, and interactions within, the physical world.

B. Epistemic beliefs about the content of physics knowledge

Participants' epistemic beliefs varied across the continuum (see Fig. 3). Participants' epistemic beliefs about the content of physics knowledge were characterized as either tending toward mathematics (based on formulas) or conceptual (and qualitatively explained).

Participants placed on the extreme end of the continuum representing the belief that physics knowledge was conceptual and qualitative (shown at the extreme right of Fig. 3) identified mathematics as a tool, not necessarily how we know physics. Each of these participants claimed that it was possible to understand physics without mathematics. Conceptual physics knowledge, to these participants, was a deeper way of knowing physics; "I think when you get to upper level then things become more conceptual in physics," (Marcos). Those participants most strongly voicing the epistemic belief that physics knowledge was conceptual claimed that mathematics was a tool that described what to do with an understanding of physics, which these participants described as knowing why something happened.

Denise, Ian, and Nadia believed that physics knowledge was conceptual and qualitative but were less convinced mathematics could be removed from physics. These three participants were placed to the right of center in Fig. 3. These participants also believed that knowing mathematics was integral to knowing physics, but that physics knowledge was conceptual and qualitative. These participants saw physics knowledge as conceptual and qualitative at its core. However, Ian went on to explain how physics required mathematics; "I suspect that you need some significant mathematical tools to be able to do more than just blow hot air about physics." To these participants,

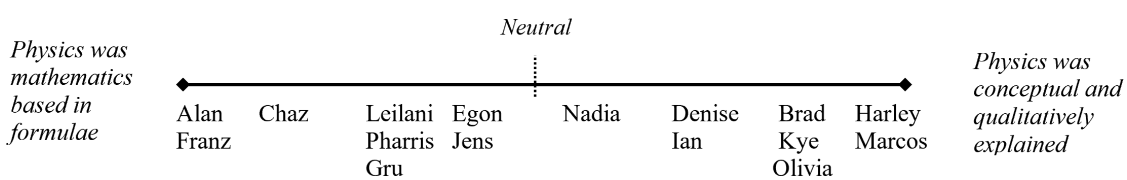

FIG. 3. Continuum of epistemic beliefs about the content of physics knowledge with participants placed.

physics knowledge was certainly conceptual, but knowing and employing mathematics was also necessary for knowing physics.

Egon, Leilani, Jens, Pharris, and Gru (placed to the left of the centre in Fig. 3) believed that physics knowledge was rooted in mathematics but also somewhat conceptual. These participants described mathematics as necessary proof for a deep understanding of conceptual ideas in physics. Leilani exemplified their beliefs,

> I also think [physics knowledge was in] the mathematics like going down an inclined plane how mass is irrelevant. So, we have that concept and we talk about dropping a feather and a penny and air resistance and stuff but then we'll show it doing a demo and then we'll prove it mathematically—how the masses cancel out.

This exemplar quotation suggests that it is with mathematics that physics concepts are proven. These participants communicated that mathematics provides evidence for the conceptual side of physics.

To Alan, Chaz, and Franz, all represented near the extreme left of Fig. 3, mathematics was the evidence of knowledge in physics and the discipline of physics was defined by its problem-solving focus. Franz claimed, "math is the way you explain everything because math is data—physics is math…math is what helps you justify data, justify your explanations and all that is through math." To Franz, mathematics served as the evidence of knowledge in physics; it was through data (synonymous with mathematics for Franz) that physics knowledge was defined. For Alan, mathematics was essential to physics knowledge; "one of the fundamental ideas [of physics] is a really strong understanding of math, trig, and algebra." Chaz was grouped with these participants but slightly more towards the middle of the continuum in Fig. 3 since he described mathematics as central to knowing physics but not as *the way* we know physics. He expressed that a person might be able to acquire some understanding of physics without mathematics but challenged the idea of entirely conceptual knowing claiming that the content of physics was primarily mathematically oriented.

C. Epistemic beliefs about the certainty of physics knowledge

As shown in Fig. 4, all participants expressed the belief that physics knowledge was tentative and likely to change. Those most strongly agreeing that physics knowledge was tentative (furthest right on the continuum) voiced the opinion that change in physics was something expected within the science community. For example, Olivia, a physics teacher who had previously worked as a field scientist, claimed that the idea that science (particularly physics) is unchanging was a common misconception.

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

Those participants placed at the extreme end of this continuum communicated that "science is very dynamic and it changes" (Marcos) and that physics was not only likely to change but that physics "needs a shakeup—something has to change" (Brad). Participants voicing that physics knowledge was tentative described the field of physics as something that regularly changes.

Those participants placed nearer the middle of this continuum communicated the belief that physics knowledge was likely to change but were reluctant to agree that the fundamental ideas of physics could change. Participants in this group claimed that newer ideas in physics could change but those ideas that were foundational to physics knowledge were unlikely to change. Kye explained that whether physics knowledge was tentative depended on the physics concepts being considered.

> Gravity on Earth is not going to change unless the mass of the Earth changes (which hopefully won't happen). But I think when we start getting to the edges of physics with stuff like subatomic particles and trying to figure out some of the

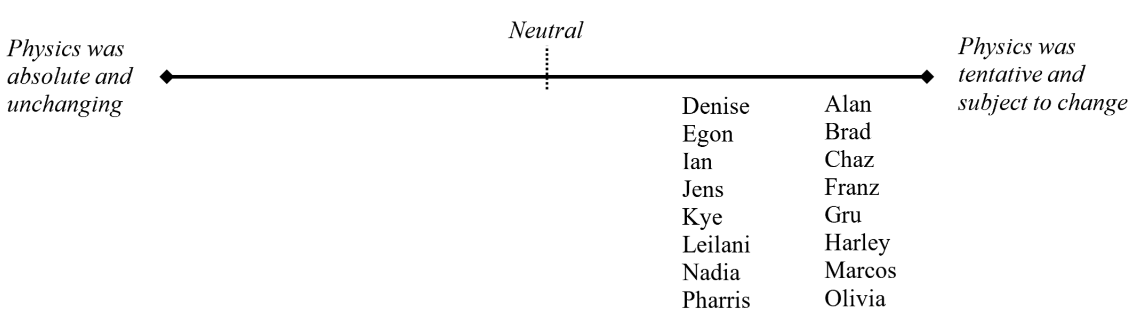

FIG. 4. Continuum of epistemic beliefs about the certainty of physics knowledge with participants placed.

> bigger questions of the universe, then, yeah, that will change (Kye).

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

D. Epistemic beliefs about the structure of physics knowledge

Most (15 of 16) participants expressed the belief that physics knowledge was at least somewhat coherent and connected. Figure 5 shows the placement of participants along the continuum of epistemic beliefs about the structure of physics knowledge. Participants strongly believing that physics knowledge was coherent (depicted as being part of the rightmost grouping on Fig. 5) commonly supported the suggestion that physics ideas were connected through concepts such as motion (Chaz, Egon, and Olivia) or through mathematics (Franz). Participants at this extreme on the continuum of epistemic beliefs about the structure of physics knowledge described physics knowledge as being consistently coherent and easily connected through concepts and ideas.

The second grouping of participants—placed nearer neutral but still believing physics was a coherent system of connected ideas—reported a caveat to physics knowledge being constructed of coherent ideas. These participants referred to the ongoing search for a grand unified theory. "Can [ideas in physics] all be connected? I think they can, but I don't think we're there yet […] we still need to make those connections" mentioned Denise. Her sentiments were echoed by Jens, who, when asked whether we can connect all the ideas in physics said, "well, they're trying, they haven't succeeded yet, right?" To these participants, physics knowledge was coherent and connected, but not completely so. However, they were hopeful that one day these final connections would be made.

Unlike her colleagues, Nadia believed that physics concepts cannot always be connected. Nadia indicated that some aspects of physics were connected but other aspects were separable:

> Some [ideas in physics] are very related and some you can totally separate. [In grade 11 physics] we talk about mirrors and lenses, [and] it's very different from forces and motion [in grade 12 physics] so I think there's some [ideas] that can be separated.

When probed for clarification regarding the separation of physics ideas, Nadia continued to return to the separable aspects of physics as the content in the school curriculum. She went on to say, "I think physics is so broad; that there are so many ideas. I feel like every *unit* [emphasis added] there are different ideas." This comment differed from those discussing physics as a coherent system of ideas, who referred to physics as a field of knowledge.

VI. DISCUSSION

Epistemic beliefs research relies heavily on quantitative research approaches; however, these approaches are not always best suited to capture epistemic beliefs. Scholars (e.g., [3,25,26]) have argued that traditional survey approaches (i.e., Likert scales) may not accurately represent epistemic beliefs. Surveys typically represent epistemic beliefs in a binary format. That is, an individual believes one aspect of the epistemic belief to be true, or the other. This misrepresents the complexity of epistemic beliefs since it, as Hilpert and Marchand [96] explain, reduces a complex problem to a simple but inadequate model. Finally, many epistemic belief surveys studies do not report measurements of reliability or validity [14], but those studies that do have historically accepted results that have low consistency and lack replicable factor structures [26,51]. Hence, we question the suitability of quantitative measurements to appropriately represent epistemic beliefs.

A significant barrier to using qualitative research to investigate epistemic beliefs is the time required for data collection and analysis. As described by Lee *et al.* [14], "due to the complexity of the target phenomena and the limitations of the currently available analysis tools, qualitative methods are often time-consuming" (p. 899). The nature of qualitative research requires more time for data collection and analysis, particularly when using thick

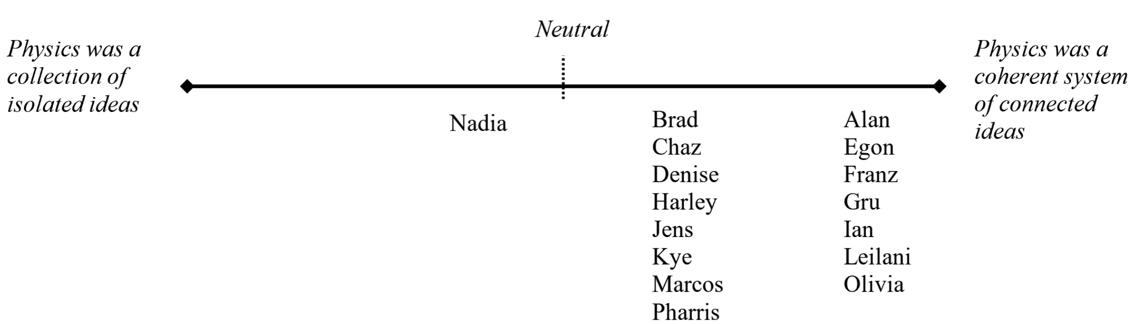

FIG. 5. Continuum of epistemic beliefs about the structure of physics knowledge with participants placed.

descriptions to represent the data. However, the four continua of epistemic beliefs about physics provide researchers with a tool with which they can sift through data more dexterously than when compared to using grounded theory approaches. Using these continua, including the defined groups of potential responses, researchers can efficiently visualize the epistemic beliefs about physics reported by a group of participants.

Using thematic analysis, we have shown the potential for using a visual representation (continua) when analyzing epistemic beliefs about physics knowledge. As discussed by Elby [3], Lee *et al.* [14], and Watson [26], qualitative research can provide the nuance required for epistemic beliefs research. Analyzing epistemic beliefs about physics knowledge using continua represents such a nuanced approach and a means of reporting and reviewing the epistemic beliefs of individuals and groups. Using continua to represent epistemic beliefs about physics knowledge also responds to scholars (e.g., [62,63]) calling researchers to shift from binary representations of epistemic beliefs to modes of representation offering a more fine-grained understanding of these beliefs. This study has described four continua, consistent with the literature and refined using participant responses and member checking, which can be used to represent individuals' epistemic beliefs about physics knowledge.

A. Using the continua in future studies

We propose four continua, shown in Figs. 6–9, with which other physics education researchers might represent qualitative investigations of epistemic beliefs about physics knowledge. On each of the continua represented in Figs. 6–9, brief descriptions are provided for the broad themes describing the beliefs of individuals placed in each of the bracketed spaces. We note that the presented descriptions are based on our context and work with Western-Canadian teachers. As qualitative researchers, we present these figures as a point from which other researchers may consider transferring our findings and processes to their work. We do not offer these continua as a generalization of our findings since our research, as qualitative work, is highly contextual. However, with further research, this continua-driven framework might be refined and adapted for use within other contexts.

As mentioned, this method of data analysis still allows for a visual representation of beliefs and epistemic profiles but is a viable and distinct alternative to Likert scale data collection. Using continua, more nuanced and transferable representations of each area can be provided. The method we have detailed represents the meaning of participants' responses (as they agreed) with more clarity than a number on a Likert scale (which is often left entirely to participant and reader interpretation). Further, our continuum groupings were built from participant responses instead of forcing participants into predetermined groupings (i.e., choices on a Likert scale), as is often the norm in epistemic beliefs research. Researchers can use these descriptions in member checking to ensure that participants' beliefs are accurately represented and that placements are appropriately inferred. Alternatively, researchers might ask participants to place themselves using the descriptions provided.

Further, this method extends in a positive manner the use of profiles in epistemic beliefs about physics research since it allows for ambiguity in participant responses. In Figs. 6–9, each of the continua has been presented with overlapping areas describing the represented beliefs found in this study and the literature. Each continuum has four bracketed spaces, but these spaces are not necessarily distinct from each other; there is some overlap. Unlike a forced-choice Likert scale, this approach allows participants to fall into multiple defined spaces. We suggest that these overlaps are also negotiable and depend on context, participants, and the area of physics being considered. The reasons for placement nearer neutral in each of the presented spaces on each continuum are indicated using arrows above the continuum. Using these measures, researchers can present epistemic beliefs profiles with more nuance than is available using quantitative approaches. Yet, with these measures researchers can represent qualitative

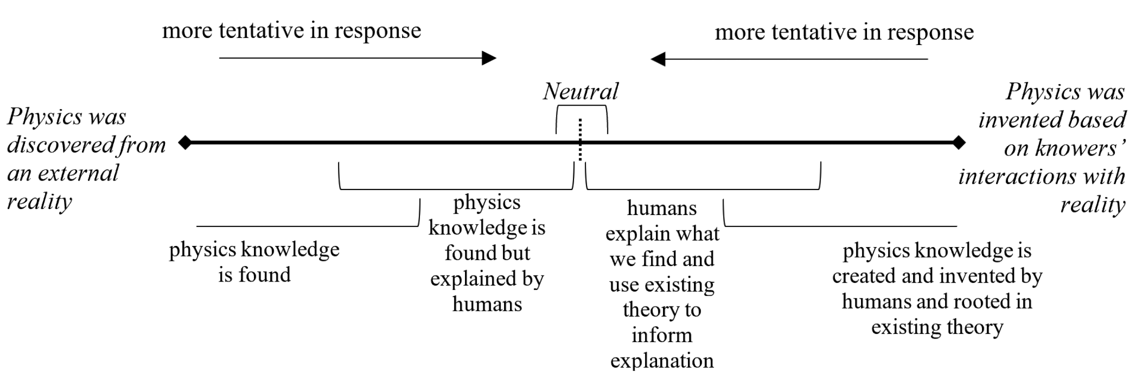

FIG. 6. Continuum of epistemic beliefs about the source of physics knowledge.

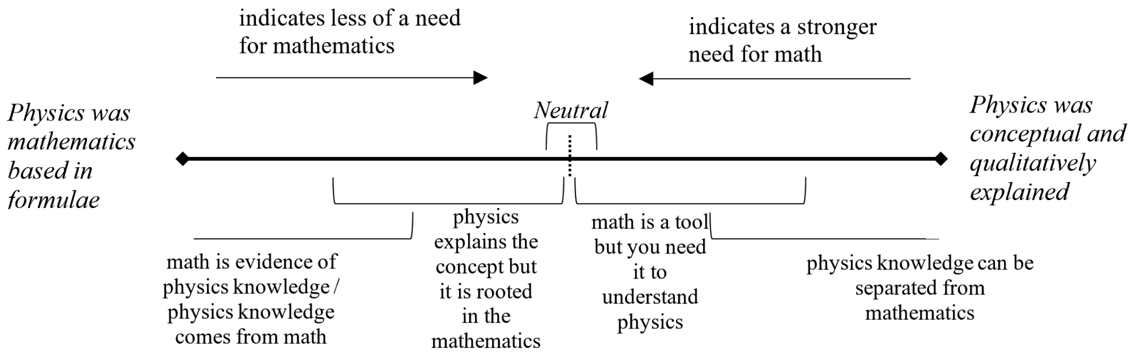

FIG. 7. Continuum of epistemic beliefs about the content of physics knowledge.

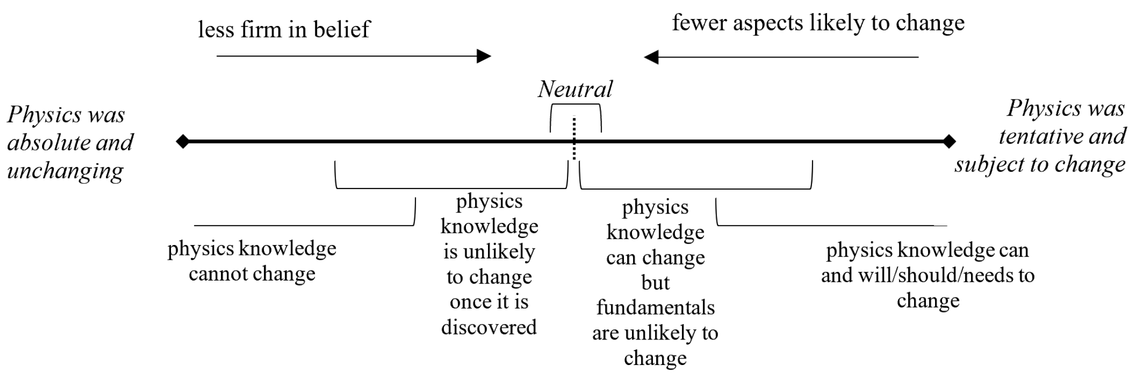

FIG. 8. Continuum of epistemic beliefs about the certainty of physics knowledge.

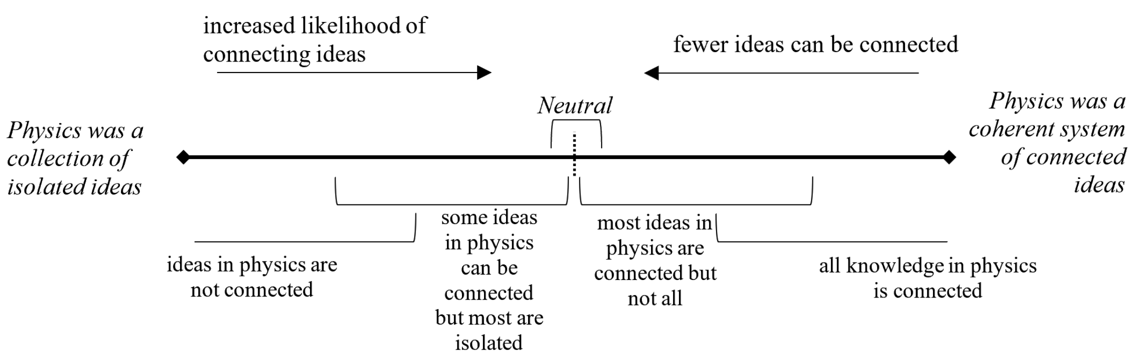

FIG. 9. Continuum of epistemic beliefs about the structure of physics knowledge.

epistemic beliefs research with the clarity and straightforwardness afforded to quantitative profiles.

The analysis of interview data can take much more time than survey data analysis and the results from a group of individuals can be difficult to synthesize. The method discussed in this manuscript, while it does not necessarily lighten the intense (but important) workload of analyzing interview data, provides researchers with a way of visually synthesizing individual profiles to better understand the belief profiles of a group. Over time, the collection of group belief profiles may lead to insights about a specific contextual group (e.g., students enrolled in a first-year physics course offered at a specific university). Another benefit is that this approach allows researchers to consider how epistemic beliefs connect more easily to other constructs. For example, Watson [60] compared individuals' epistemic beliefs about physics to their concerns about a physics curriculum document using matrices with the continua of epistemic beliefs along one axis of the matrix and individuals' concerns along the other. This visualization provided insights into the patterns she claimed to find between the two constructs: improving the trustworthiness of this type of qualitative research. Further, qualitative research often uses member checking (checking that the interpretations of a researcher accurately represent the intended meaning of a participant) to ensure the accuracy of their findings. By representing individuals' beliefs on continua, researchers can quickly member check whether their interpretations match where a participant might represent their epistemic beliefs.

B. Implications

This study presents a way of visualizing qualitative data to capture the nuance of epistemic beliefs. As we have suggested, using continua to analyze individuals' epistemic beliefs about physics knowledge has the potential to provide researchers with a more refined way of representing beliefs than can be offered at this time by quantitative analysis alone. Along with the benefits to research, these continua can also offer physics instructors insight into their students' epistemic beliefs about physics knowledge as individuals and as a collective. In using these continua in classrooms, instructors can prompt necessary and important conversations about the nature of science, personal epistemology, and variance in epistemic beliefs.

In teaching her science methods courses (intended to prepare future science and physics teachers), the first author of this paper has students self-report where they believe they fall on each of these four continua and explain why they place themselves at each of these points. Students then enter their responses into a student response system. Classwide responses are shared, and students recognize that—despite being educated in science (many have previous undergraduate degrees in science)—they hold varying epistemic beliefs about science knowledge. Throughout the term, these ideas about what it means to know something in physics and how we come to know new ideas in physics are revisited and discussed but grounded in their experiences. For those sections with students seeking to teach biology and chemistry, the perceived differences between the sciences and how this might impact how we teach and learn are also discussed.

Similarly, we anticipate the use of continua in physics classrooms to collect students' epistemic beliefs about physics knowledge as a beneficial tool for physics instructors. Research has shown that students with more sophisticated epistemic beliefs tend to produce more scientific arguments and better-quality scientific arguments [20]. Hence, it is important that physics instructors help develop students' epistemic beliefs as part of understanding physics as a discipline.

C. Limitations

The interpretation and findings of this study were impacted by its small sample size and context. First, this study used a small sample size ($N = 16$) from which to develop these continua. Small sample sizes are common in qualitative research because of the laborious analysis required of qualitative datasets. According to Brinkmann and Kvale [97], interview studies commonly use 5–25 participants; this study falls within this range. However, compared to quantitative studies, this sample size is quite small. Given more interview data, with different populations, these continua descriptions would possibly be refined. Yet, the small size of this population allowed sustained contact with each of the participants, providing space for member checking of researcher interpretation. This member checking lends power to our conclusions as we are making fewer assumptions about participant meaning and ensuring that participants' intended meaning and beliefs were accurately represented.

Second, this research was conducted with a specific population, secondary teachers, in a specific context—a Western Canadian province. This context would certainly influence these responses as teachers in this province had been teaching from the same 30-year-old curriculum documents at the time of this study. As qualitative researchers, we recognize these potential biases. Qualitative research is not meant to be generalized [87,97] but offers a starting point to develop these continua. Conducting similar studies with different populations (e.g., different age groups) and in different locations could further develop gradation across each of these continua.

Finally, we have noted throughout this work that we intend these continua to be used to describe individuals' epistemic beliefs about physics. This approach might be extended in future research to further explore individuals' understanding nature of science (or nature of physics). However, this extension requires careful thinking about how one defines the epistemology of physics, and whether we can claim philosophers of physics would agree on an appropriate placement along each continuum. The best we can do is provide data as evidence for our assertions. Further, researchers with the intention of using this approach to explore the nature of science might wish to include other aspects of the nature of science that are not traditionally included in science education research exploring epistemic beliefs such as the role of models and simulations, objectivity and the social nature of science, and diversity. Research of this type might begin to differentiate between epistemological misconceptions from inadequate beliefs.

VII. CONCLUSION

This study describes four continua that could be used to describe how individuals conceptualize physics knowledge—their epistemic beliefs about physics knowledge. Epistemic beliefs about physics knowledge are commonly researched using quantitative survey methods but these methods have been heavily criticized. Using qualitative research methods and representing epistemic beliefs along continua instead of using binary approaches, allows researchers to better represent the gradation of beliefs. Using these continua, researchers can better capture the nuance of epistemic beliefs, effectively member check interpretations, and compare epistemic beliefs with other constructs. Instructors can use these continua to quickly visualize their students' individual epistemic beliefs as well as collate the beliefs of an entire class. These continua offer the well-established field of epistemic beliefs research in physics education a novel way to visualize qualitative research.

ACKNOWLEDGMENTS

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