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The Development of Teachers' Epistemic Beliefs about Science: A Review of the Literature

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ABSTRACT

Empirical research studies investigating teachers' epistemic beliefs about science are scattered across the science education literature. This research summarizes and describes the literature investigating the development of teachers' epistemic beliefs about science over the last 25 years. The focus of this summary is on how teachers' epistemic beliefs about science have been investigated and conceptualized as well as the themes arising from empirical studies considering this construct. Using a systematic literature review (PRISMA protocol), empirical research studies investigating the development of teachers' epistemic beliefs about science were identified. Thematic analysis was used to analyze, summarize, and interpret data. Findings indicate that teachers' epistemic belief development is commonly studied using interventions to instruct teachers about and engage them with the epistemic underpinnings of science. The nature of science was the most frequently used framework to conceptualize teachers' epistemic beliefs about science, with few studies using approaches more common in the general epistemic belief or epistemic belief development literature. Reflections on and interpretations of the summary of this systematic literature are provided, including potential considerations for future directions of research investigating the development of teachers' epistemic beliefs about science.

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INTRODUCTION

Teachers' epistemic beliefs refer to their attitudes, values, and knowledge about the nature of knowledge and how it is generated in a particular field of study, such as science. Formulated based on one's epistemology, or philosophy of knowledge, epistemic beliefs can be considered to describe how an individual conceives of knowledge and how we come to know (Dolphin & Tillotson, 2015; Moshman, 2015). For example, does a teacher perceive science knowledge to be absolute and unchanging or is science knowledge tentative and subject to change? Or does a science teacher see science knowledge as lying between these two positions? Studies have described the epistemic beliefs about science of pre-service (Buaraphan, 2010; Guilfoyle et al., 2020; Ogan-Bekiroglu & Arslan-Buyruk, 2018; Pérez & Díaz-Moreno, 2022) and in-service (Kite et al., 2021; Liu & Roehrig, 2019; Park et al., 2022; Tsai, 2002; Watson, 2021b) teachers. However, studies typically described teachers' epistemic beliefs at a particular moment in time. In this study, we ask what the field knows about the development of teachers' epistemic beliefs about science.

Science is so much more than content, and education should reflect this (McPeck, 1984). Science education researchers have been pushing for a change from fact-based science education to one incorporating the nature of science for decades (Kite et al., 2021; Nouri et al., 2021; Tobin & McRobbie, 1997). The nature of science can be described as the epistemic criteria of science knowledge (Deniz, 2017)—meaning that the nature of science describes how scientific knowledge is characterized. However, recent research shows that science teachers may not always espouse the epistemic beliefs communicated by expert scientists or philosophers of science when it comes to the nature of science (Nouri et al., 2021; Watson, 2021a). It is imperative that science education researchers consider the development of teachers' epistemic beliefs about science to better understand how we might prepare teachers with appropriate understandings of the nature of science.

It is troubling that those epistemic beliefs expressed by some science teachers do not align with the nature of science. This disconnect in beliefs and philosophy is concerning because research has also shown that students' development of their epistemic beliefs is highly influenced by their educational experiences and teachers (Muis, 2008; Nouri et al., 2021; Yavuz, 2014). Research on teachers' epistemic beliefs has shown that these beliefs have a significant impact on their teaching practices, including the selection of instructional strategies (Kurup, 2014; Maggioni & Parkinson, 2008), the interpretation of scientific concepts (Murphy & Alexander, 2016; Vasconcelos & Kim, 2022), and the evaluation of student learning (Barnes et al., 2020; Baytelman et al., 2020; Fives et al., 2017). Further, according to Sengul (2020), teachers who hold strong epistemic beliefs about the stability and objectivity of scientific knowledge tend to emphasize the transmission of information and the importance of memorization; whereas those teachers recognizing knowledge as a human endeavour that is subjective to change tend to highlight the process of inquiry and the development of scientific reasoning skills. The development of teachers' epistemic beliefs is of great importance since we, as teacher educators, want to develop future science teachers holding beliefs that espouse the nature of science.

The aim of this literature review is to synthesize those recent studies that have contributed to our understanding of the epistemic beliefs of science teachers (and the development of these beliefs). Among other outcomes, knowing what has developed teachers' epistemic beliefs can help guide teacher education—for both in-service and pre-service teachers—to enact appropriate measures to foster the development of teachers' epistemic beliefs about science knowledge. If science educators have a better knowledge of how to effectively develop these beliefs, we can better prepare our teachers to convey appropriate understandings of the nature of science to their students. However, to know how to effectively do this, it is necessary that the literature on teachers' epistemic belief development be synthesized to guide future research in this direction. That is, what do we, as educational researchers, understand about the development of teachers' epistemic beliefs about science?

A growing area of educational research, epistemic beliefs research has been increasing in popularity in science education (Lee, Luan, et al., 2021). For example, a search of the Journal of Research in Science teaching shows over 300 articles (of approximately 4300 articles) discussing epistemic/epistemological aspects between 2013-2023. This is up from 200 articles between 2003-2013. In such an active area, it is necessary to have studies that synthesize our knowledge on aspects of this research. Studies have synthesized work in epistemic beliefs; Schiefer et al. (2022) recently provided a systematic integration of multiple studies investigating epistemic beliefs and Lee (2021) described themes in methodological approaches investigating epistemic beliefs in science. There are also entire books such as (Bendixen & Feucht, 2010), Hofer and Pintrich (2002) and Schraw (2017) describing the landscape of epistemic beliefs research at key points. Contributing to this rapidly developing area, this study sought to explain our current understanding of the development of teachers' epistemic beliefs about science knowledge.

Background

Epistemic beliefs research has been of interest to educational researchers for over 50 years. The field of epistemic beliefs research in education has had two main veins—(a) epistemic belief development and (b) describing multi-dimensional epistemic belief profiles. Historically, educational researchers were first interested in epistemic belief development and considered epistemic beliefs to be domain-general. In the early 1990s, there was a shift to considering epistemic beliefs as multi-dimensional and domain-specific. Epistemic beliefs can be described and conceived of in many ways, hence, we, the authors, use this section to describe the debates and understandings common in the field of epistemic beliefs

Epistemic Beliefs

Beliefs research, in general, is messy (Pajares, 1992) and to claim one can neatly define these terms—separable from the others—would misconstrue the field. Given this convolution, as suggested by Pintrich (2002), it is important that researchers investigating epistemic beliefs (or personal epistemology or epistemological beliefs) describe how they interpret the term (Schommer-Aikins, 2002). This field of research uses many terms to define similar, yet slightly different, ideas. For example, the term *epistemic beliefs* has been used to describe (1) an individual's knowledge and beliefs about knowledge (B. K. Hofer & Pintrich, 1997; Kitchener, 1983) and (2) an individual's beliefs about knowledge (Murphy et al., 2012). Researchers have also used the term *personal epistemology* as describing an individual's knowledge and beliefs about knowledge (B. K. Hofer, 2002; Pintrich, 2002). To make things more complicated, researchers often interchange these terms (B. K. Hofer & Bendixen, 2012; Schommer-Aikins, 2002; Schraw et al., 2017). For example, Walker et al. (2020) when defining the term 'epistemic beliefs', use the definition that Hofer and Pintrich (2002) use to define 'personal epistemologies'; this practice is common in this field of research.

In this study, we use the term 'epistemic beliefs' to describe an individual's perception of how knowledge is conceptualized. However, these authors recognize that other researchers may use the term personal epistemologies, epistemological beliefs, or views/understandings of the nature of science to describe the same (or a very similar) construct.

Epistemic Belief Development

Education researchers interested in epistemic beliefs have explored the development of epistemic beliefs (Kuhn, 1999; Perry, 1970), students' epistemic beliefs (Leung, 2020; Martins & Lindsay, 2022; Schiefer et al., 2022; Zetterqvist & Bach, 2023), teachers' epistemic beliefs (Mohamed, 2014; Olafson & Schraw, 2010; Park et al., 2022), and the domain-specificity of epistemic beliefs (e.g., Buehl et al., 2002; Hofer, 2006). Much of the more recent work in this field has focused on the representation of epistemic beliefs using multi-dimensional models since the work of Schommer (1990, 1993, 1994). Research about epistemic beliefs has also turned from exploring epistemic belief development to studies aimed at describing epistemic beliefs. Studies have described epistemic belief development in science, but most focused on the development of students' epistemic beliefs about science.

Researchers have sought to explain the development of epistemic beliefs. Since Perry's (1970) work with college students, epistemic beliefs have been of interest to educational researchers. His work developed one of the earliest models describing the development of epistemic beliefs, paving the way for researchers to investigate this construct. Belenky et al. (1986), Baxter-Magolda (1987), King and Kitchener (1994), and Kuhn (1991) are all examples of epistemic beliefs research centred on the development of epistemic beliefs. For a good summary of these models, we recommend reading Hofer and Pintrich (1997), a seminal article which nicely synthesizes epistemic beliefs research up until that point in time.

Early studies investigating a developmental view of epistemic beliefs focused on differentiating stages through which individuals commonly evolve as their epistemic beliefs develop. As one example, Kuhn and Weinstock (2002) built a seminal model describing different stages of epistemic beliefs through which an individual passes over the course of schooling: realist, absolutist, multiplist, and evaluativist. This work was built on previous studies and heavily drew on the work of Perry (1970) who claimed that students followed a consistent educational journey through various epistemic positions. To Kuhn and Weinstock, realists assumed that knowledge was acquired from external authorities and that knowledge replicated an external reality. As individuals' epistemic awareness developed, individuals moved into being absolutists–perceiving knowledge as "absolute, certain, non-problematic, right or wrong," (Kuhn & Weinstock, 2002). Multiplists view knowledge as a human-generated construct and question the certainty of knowledge, since they recognize that some knowledge might be considered opinion. Those who reach the evaluativist level recognize that humans have a shared understanding of the work but that some positions of knowing–such as experts–are more supported than others. Despite using slightly different language, models describing epistemic development.

Major criticisms of these developmental models were that they were unidimensional and domain-general. Each of these models described epistemic beliefs as existing in one dimension, with all aspects of our epistemic beliefs developing together. A second criticism of developmental models is that they are all domain-general, that is that epistemic beliefs are considered the same for all areas of knowledge. In these models, participants' epistemic beliefs about science were considered to progress similarly to those in another subject area. As a result, and with Marlene Schommer's work in the early 1990s, there has been a shift in research investigating epistemic beliefs to multi-dimensional and domain-specific models. Along with this shift in epistemic models, also came a focus from exploring epistemic development to describing epistemic belief profiles of participants.

Multi-Dimensional Epistemic Beliefs

Researchers of epistemic beliefs have come to the consensus that epistemic beliefs can be described by multiple, more-or-less independent dimensions. However, there is a lack of agreement on the specific dimensions used to describe epistemic beliefs (B. K. Hofer, 2016; Schiefer et al., 2022). Although the specific dimensions vary, recent research typically conceives of epistemic beliefs using multiple dimensions. For example, Schiefer (2022), use a four-dimensional model of epistemic beliefs. In summarizing methodological approaches to measuring epistemic beliefs, Lee (2021), describe seven surveys that are commonly used to describe epistemic beliefs. These seven surveys use sub-construct approaches that describe dimensions of epistemic. As an example, the Scientific Epistemic Beliefs' (SEB) Questionnaire, developed by Conley (2004), uses a four-dimension structure of beliefs and was the most frequently used survey in Lee (2021) and colleagues' study. In this turn to the multi-dimensional models of epistemic beliefs, researchers largely focused on epistemic belief profiles instead of considering epistemic development.

There are a few studies in recent literature that have sought to combine the multi-dimensional and developmental approaches to epistemic beliefs research. Two notable studies include Feucht (2017) and Lee (2021). Feucht (2017) combined Kuhn (1999) levels of epistemic development with B. K. Hofer (2001) four dimensions of epistemic belief. The combination of these two models left Feucht with a 12-cell matrix, which they used to describe the epistemic climate of a fourth-grade science curriculum. Drawing inspiration from Feucht's work, Lee (2021) developed a 9-cell matrix using Kitchener's (1983) epistemic cognition dimensions and Kuhn's (1999) framework. Studies such as these show innovative approaches to exploring the development of epistemic beliefs while still considering these beliefs through multi-dimensional frameworks.

Scholars disagree on whether dimensions about the learning and teaching of a subject are to be included in epistemic belief models. Schommer's (1993, 1994) work includes the dimensions of Innate/Fixed Ability—whether a person's capability to learn is fixed—and Learning Effort/Process—whether the process of learning can be learned. However, this was criticized by other scholars, such as Baytelman (2020), B. K. Hofer (2001), and Watson and Thomas (2024) who do not include aspects of learning in their models of epistemic beliefs. Further, one of the most used models describing the epistemic aspects of science, the nature of science, does not traditionally include aspects of learning science. Typically, researchers using multi-dimensional approaches to conceptualize epistemic beliefs declare whether they include learning or not within their framework.

Finally, 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 domain-general (i.e., similar across areas of knowing or topics) (Fives & Buehl, 2017; Schommer-Aikins, 2002). Following the shift from epistemic development research to multi-dimensional epistemic beliefs, researchers began to more frequently investigate epistemic beliefs as domain-specific; this is particularly true in the research of epistemic beliefs in mathematics and science education (Hofer, 2002; Hofer & Bendixen, 2012). These authors subscribe to the belief that epistemic beliefs are domain-specific, supported by Fives and Buehl (2017) and Hofer (2012). To these writers, epistemic beliefs about science knowledge are a specific construct and may diverge from those beliefs about knowing in other subject areas. Research has shown that this is not the case. For example, found that participants' epistemic beliefs about science often differed from those epistemic beliefs about social sciences. As one example, Buehl and Alexander (2005) found that individuals held differing epistemic beliefs when considering knowing in science and knowing in history. We, the authors, align with recent research and consider epistemic beliefs about science knowledge to be a separate construct from epistemic beliefs about other areas of knowledge.

ANALYSIS AND METHODS

The main purpose of this literature review is to understand the major themes arising out of research investigating the development of teachers' epistemic beliefs about science. We aim to provide an overview of the themes in recent research as well as a description of the general characteristics of studies investigating the development of teachers' epistemic beliefs about science. Our analyses were driven by the following inquiries: (1) What research has investigated the development of teachers' epistemic beliefs over the last 25 years? (2) How is the development of teachers' epistemic beliefs about science being conceptualized in the literature over the last 25 years? and (3) What themes have researchers identified to facilitate the development of teachers' epistemic beliefs over the last 25 years?

Selection of Studies

These authors have identified a seminal study describing the field of epistemic beliefs research and continued the search forward from this study. Hofer and Pintrich (1997) described the field of epistemic beliefs shortly after the turn from development research to multi-dimensional epistemic profiles. Using this study as a pivotal point in the field of epistemic beliefs research, searches were conducted for research published between 1998 and 2023 that explored the development of teachers' beliefs.

The Preferred Reporting Items for Systematic Reviews (PRISMA) has been recognized to ensure the quality of systematic reviews and to improve its protocols (Moher et al., 2015). We used PRISMA to map out the search, this includes the PRISMA-P checklist and the PRISMA flowchart. Two databases were searched separately – ERIC ProQuest and ERIC EBSCOhost. Peer-reviewed publications were searched using the same Boolean phrase for both databases – teacher AND (epistemology OR epistemic) AND science AND (develop OR development). The search resulted in a total of 675 studies from both databases. The researchers used predetermined exclusion criteria to establish which studies were deemed eligible for analysis in this systematic literature review. Exclusion criteria as they were applied can be viewed in Figure 1, detailing PRISMA in this study. In total, 33 studies were included in our review.

Coding

33 studies were analyzed through close reading of each article that was included in the analysis. Each article was coded and analyzed according to characteristics common to studies researching teacher epistemic belief development: (1) the context and participants, (2) conceptualization of epistemic beliefs, (3) the type of research method and data analysis, and (4) the main findings related to the development of science epistemic beliefs. Each of these themes included predetermined categories. The context included details about where the study took place, the stream, the number of participants, whether they were pre-service and/or in-service teachers, and the duration of development. The conceptualization of science epistemic beliefs included the model studied and whether it included learning. The type of research method and data analysis consists of specifying if the study is qualitative, quantitative or both. It also includes a description of the methods with a breakdown of the data collection and analysis. The last category comprises whether the findings section included a description of the epistemic beliefs and the main findings related to the development of science epistemic beliefs. Findings for each of these categories are discussed in our results.

RESULTS

There has been an increase in publications about the development of teachers' epistemic beliefs in the last 25 years. Of the analyzed studies, four were published between 1999 and 2005, seven between 2006 and 2010, eight between 2011 and 2015, five between 2016 and 2020, and nine since 2021. This shows that the development of teachers' epistemic beliefs is small but of growing interest to science education researchers.

Conceptualization of Epistemic Beliefs

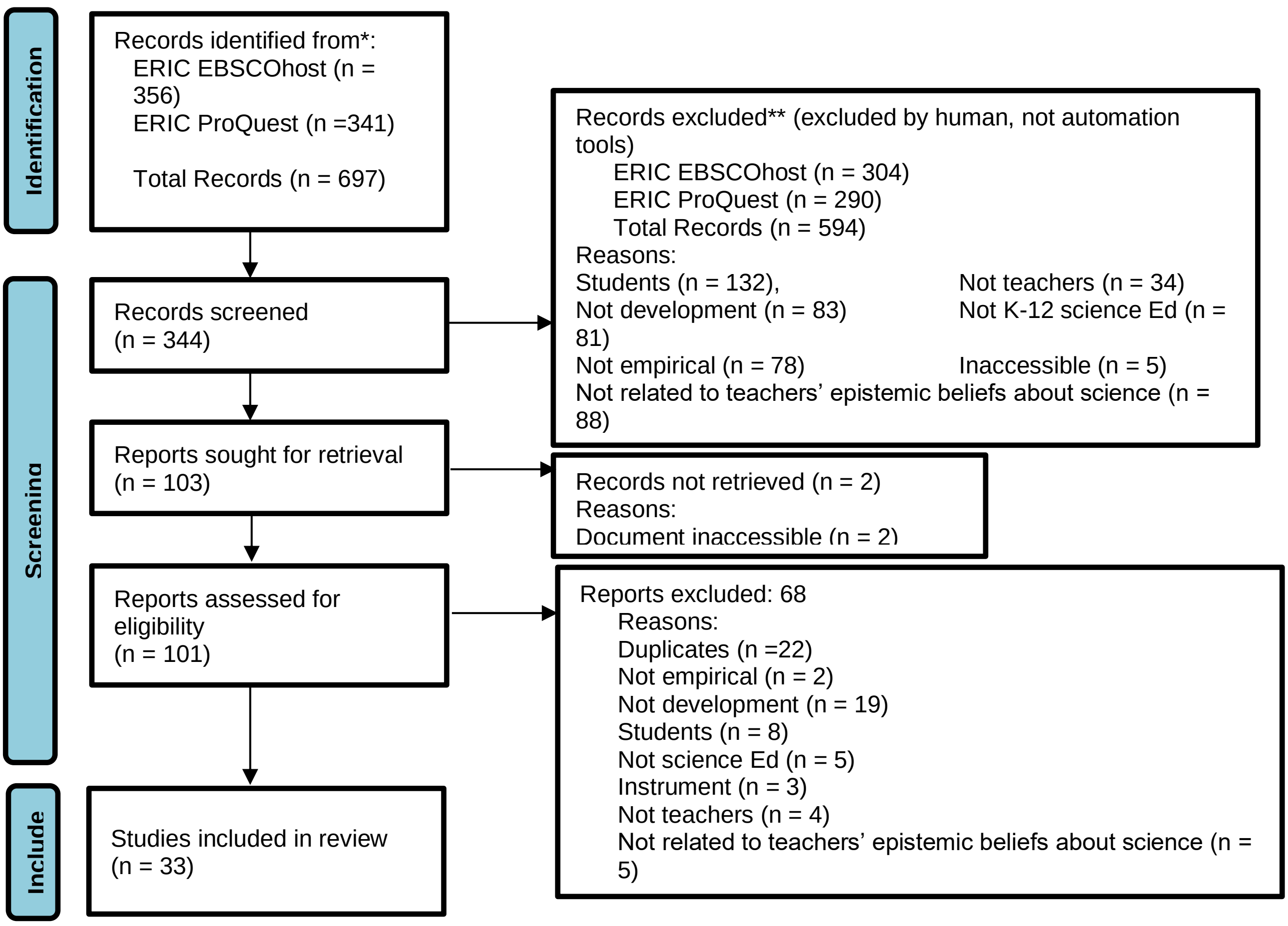

Figure 1. Prisma flowchart diagram

Most (30 of 33) studies explicitly discussed or implied the framework with which they conceptualized epistemic beliefs. Three studies discussed epistemic beliefs (or a variation of this term) but did not provide specific frameworks to explain how this construct was conceptualized. Anderson (2006) do not include a specific framework with which to discuss epistemic beliefs but describe studying pre-service teachers' epistemologies and pedagogies of teaching and learning in relation to an experiential science setting. Veal (2004) was studying teachers' beliefs broadly—one aspect of which was epistemic beliefs—and how pedagogical content knowledge interacted with these beliefs; the focus is on defining teacher beliefs and pedagogical content knowledge, but epistemic beliefs are not formally defined. Additionally, López-Banet and Martínez-Carmona (2021) allude to their conceptualizations of epistemic beliefs, but they are not defined for the reader. In reading this work, Lopez-Banet and Martinez-Carmona (2021) integrate teaching and learning with teachers' epistemic beliefs about chemistry (as they are working with chemistry teachers) but there is no formal definition made about epistemic beliefs themselves. All 30 of the studies which did indicate a framework to describe epistemic beliefs about (or beliefs about epistemic aspects of) science are indicated in Table 1.

The Nature of Science

Of the 30 papers discussing their conceptualizations of epistemic beliefs about science, most (n = 16) used the nature of science as a framework. Typically, the studies using the nature of science (NOS) as a framework were considering teachers' views or knowledge about the NOS. In this field, there were two common approaches used—the consensus view and the Family Resemblance (FRA) model. 12 of these 16 studies used some form of the consensus view of the NOS, which we coded as NOS-Consensus. Eight of these 12 studies explicitly described how they conceptualized the NOS. Four studies did not explicitly describe how they conceptualized the NOS but this framework was implied by the instruments they chose to use. For example, Dolphin and Tillotson (2015) used the Beliefs and Nature of Science Interview Protocol (BNOS) developed by Richardson and Simmons (1994) to describe teachers' epistemologies of science; BNOS based in a consensus view of the NOS so it implies that these researchers conceptualized teachers' epistemic beliefs using an NOS-consensus perspective.

Table 1. Summary of conceptual frameworks used to describe epistemic beliefs about (or beliefs about epistemic aspects of) science

Framework	Studies	Learning	Teaching
NOS-Consensus (n=12)	Abd-El-Khalick & Lederman, 2000; Anderson & Clark, 2012; Dolphin & Tillotson, 2015; Donohue et al., 2020; Erumit & Yuksel, 2023; Konnemann et al., 2018; Kurup, 2014; McDonald, 2010; Niaz, 2008; Ozgelen, 2012; Pérez & Díaz-Moreno, 2022; van Uum et al., 2021	3	5
NOS-FRA (n=3)	Barak et al., 2023; Erduran & Kaya, 2018; Voss et al., 2023	0	0
Multi-dimensional EB model (n=4)	Belet & Given, 2011; Deniz, 2011a; Kang, 2008; Mohamed, 2014	2	0
EB Development (n=1)	Kang, 2007	1	1
Other epistemic frameworks (n=7)	Dai, 2022; Jaber et al., 2022; Maor, 1999; Ogan-Bekiroglu & Arslan-Buyruk, 2018; Vasconcelos & Kim, 2022; Windschitl et al., 2008; Windschitl & Thompson, 2006	1	4

Framework	Studies	Learning	Teaching
Other frameworks with epistemological aspects included (n=5)	Bencze, 2010; L. Bencze & Elshof, 2004; Davidson et al., 2022; Nilsson, 2014	2	2

Three of the studies using the NOS as a framework described using the family resemblance approach (FRA) to NOS (NOS-FRA). All three of these studies had one or both creators of the FRA on the research team. It should be noted that since FRA to NOS has only been in the literature since 2014, this conceptualization of the epistemic aspects of science was only present in more recent studies (2018, 2022, and 2023 publication dates). In all three of these studies, FRA was discussed explicitly, thoroughly laid out early in the article and gave clear direction to the data analysis. In general, the NOS, whether it be the consensus model or FRA was most used to conceptualize the epistemic aspects of science through which teachers' beliefs were described.

Multi-Dimensional Epistemic Beliefs

Another way that epistemic beliefs about science were conceptualized in these studies was using a multi-dimensional approach to epistemic beliefs. As previously described, multi-dimensional frameworks are the most common way that epistemic beliefs are conceptualized in the personal epistemology literature and often used to capture epistemic beliefs in the science education literature, hence we included a brief analysis of these frameworks. Four studies used a multi-dimensional framework to describe teachers' epistemic beliefs about science. Dimensions included beliefs about the certainty, justification, source, and structure of science knowledge as well as beliefs about the attainability of truth in science, one's ability to learn science, and the effort it takes to learn science. Table 2 indicates the studies that used a multi-dimensional approach to describing epistemic beliefs and showcases which dimensions were represented within each study.

These dimensions typically were connected to the work of Schommer (1993, 1994) or Hofer (2001). Schommer's work, and those applying her dimensions, included learning dimensions such as those concerned with beliefs about the "ability to learn" (whether learning in science depends on one's ability to do so) and "learning effort" (whether one's ability to learn on science relied on their efforts to do so). Hofer's work, and those following her dimensions, did not include beliefs about the learning of science but, instead, included beliefs about whether scientific knowledge was about attaining knowable truths about the universe.

Table 2. Dimensions included within studies using multi-dimensional approaches to describing teachers' epistemic beliefs

	Attainability of Truth	Certainty	Justification / Source	Ability to Learn	Learning Effort	Structure
Deniz (2011)	X	X	X			
Belet & Guven (2011)		X	X	X	X	X
Kang (2008)	X	X				X
Mohamed (2014)		X	X	X	X	X

All the studies included in this analysis discussed a dimension aimed at describing the certainty of knowledge in science, that is whether knowledge in science was tentative and subject to change or absolute and unchanging. Four studies also included a dimension examining beliefs about the justification and/or source of knowledge. These dimensions (as sometimes they were included as separate dimensions) were focused on what sources of knowledge provided justification for acceptance; for example, whether one would accept knowledge from a theoretical physicist over an experimental physicist, or their neighbour over a trained scientist. Finally, three studies included beliefs about the structure of scientific knowledge which typically referred to whether scientific knowledge was a coherent set of interconnected ideas or a collection of isolated ideas and information.

Epistemic Belief Development

One study in this analysis used an epistemic development model to describe changes in teachers' epistemic beliefs. Despite having only one study use epistemic belief development as a guiding framework, we discuss epistemic belief development as a conceptualization since this systematic review is summarizing how the studies changes in teachers' epistemic beliefs. Investigating the epistemological dimension of conceptual change, Kang (2007) used an epistemological spectrum described by Kinchin (2000) to categorize teachers' epistemic beliefs. In this model, beliefs fell into one of three categories: positivist, misconceptions, or systems views. The positivist view was described by believing that students know little and that they could learn scientific ideas by being presented the correct idea. The misconceptions view was described by teachers recognizing that students hold misconceptions that obstruct the learning of science and that confronting misconceptions is the way help students learn science. In the systems view, teachers believe that students enter the class with prior ideas about science and that science education should build scientific conceptions based on students' prior knowledge and thinking skills.

Other Epistemic Frameworks

Eight studies used frameworks other than multi-dimensional epistemic beliefs and the nature of science to describe teachers' epistemic beliefs. These frameworks included epistemic cognition (Dai, 2022), epistemological framing (Jaber et al., 2021), and epistemologies of models (Ogan-Bekiroglu & Arsan-Buyryk, 2018; Vasconcelos & Kim, 2022; Windschitl & Thompson, 2006; Windschitl et al., 2008). These frameworks were still focused on epistemology but did not fit under the nature of science, multi-dimensional models of epistemic beliefs, or epistemic development.

Dai (2022) and Jaber (2021) draw on frameworks which are evolutions of the personal epistemology literature. These frameworks reflect tendrils and offshoots from the original vein of epistemic belief development literature started with the work of Perry (1970) and extended into multi-dimensional beliefs with the work of Schommer (1990). Dai (2022) used epistemic cognition as a framework since it reflects the act of acquiring, understanding, justifying, and using knowledge instead of capturing and describing a system of beliefs (as is done with epistemic belief and personal epistemology work). Jaber (2021) draw on work from the physics education researchers (Bing & Redish, 2009; Elby & Hammer, 2001, 2010) and use epistemological framing as a framework. In epistemological framing, activities are assessed in terms of epistemic expectations—activated by contextual factors—the assessor holds about the nature, sources, and processes of scientific knowledge. For example, an assessor might see a scientific activity as one aimed at making sense of a situation using everyday language or as aimed at a problem to be solved through applying equations and scientific vocabulary. Both frameworks developed from the same tradition as the multi-dimensional epistemic beliefs and epistemic-belief development literature.

Five studies focused on considering teachers' epistemic beliefs about models and model-based instruction. Epistemologies of models is an epistemic framework focused on beliefs about the purpose and use of models in developing scientific knowledge. Beliefs about the use and purpose of models are often included within the nature of science but this framework was very specific to that aspect of the nature of science. All the other studies using epistemologies of models (Ogan-Bekiroglu & Arsan- Buyryk, 2018; Vansconcelos & Kim, 2022; Windschitl et al., 2008) referred to Windschitl and Thompson's (2006) work in describing their conceptualization of this aspect of epistemic belief.

Other Frameworks with Epistemological Aspects Included

Finally, four studies included in this review included epistemological aspects within their frameworks but used frameworks focused more broadly than only epistemic beliefs. Nilsson (2014) considered teachers' pedagogical content knowledge and, within that framework, investigated changes in the epistemic aspects of pedagogical content knowledge. Bencze (2010) considered science teachers' reconstruction in two curricular domains: the conceptual and procedural domains. Using this framework, Bencze (2010) discusses the development of a teacher in their expertise about the epistemological aspect "Characteristics of Science and Technology" (p. 46). Bencze and Elshof (2004) use the scientific theory profile (attributed to Loving (1991) to conceptualize teachers' beliefs about science. This theory draws heavily on the consensus view of the NOS but is distinct in that it separates aspects into rational-real and natural-antireal perspectives. Finally, Davidson (2022) conceptualize their study through what they call "disciplinary understandings about science" (pp. 659-661) since this encompasses the epistemic, conceptual, social, material, and affective dimensions of science.

The Inclusion of Learning and Teaching

There is much debate in the field of epistemic beliefs about whether beliefs about teaching and learning science should be considered part of these belief systems. Of the 30 studies that explained their conceptualizations of beliefs about the epistemic aspects of science, nine included beliefs about learning science and 12 included beliefs about teaching science as part of that conceptualization. As one example of a study including beliefs about learning science in their framework, Kang (2008) included a dimension within their model of epistemic beliefs that they called the relational dimension which was described as between the two extremes "learning as receiving school subject knowledge and learning as answering one's own questions" (p. 484). As shown in Table 1, there is some debate as to whether beliefs about teaching and/or learning science are to be included in any framework conceptualizing epistemic beliefs. The only framework that appears to agree is NOS-FRA, which could be because the creators of the framework were involved in these three articles so there is less chance for other interpretations. The inclusion of teaching and learning in these conceptualizations could also be confounded by the fact that many of these studies were investigating teachers' epistemic beliefs in conjunction with their teaching practice (e.g., Dolphin & Tillotson, 2014; Kang, 2008), beliefs about teaching (e.g., Donohue et al., 2020), and knowledge of teaching science (e.g., Nilsson, 2014; van Uum et al., 2021). This is not a criticism of these studies, merely a noticing as science education researchers are concerned with improving science education and, at least according to these studies, developing teachers' epistemologies may hold potential for moving toward this goal.

Context & Participants

Of the 33 analyzed studies, 18 investigated the development of pre-service teacher beliefs, most often throughout a university course as part of their teacher preparation program. 14 studies investigated the development of in-service teacher beliefs, often because of a professional development experience. One study (Mohamed, 2014) investigated the changes in epistemic beliefs of both in- and pre-service teachers. Only two studies (Anderson & Clark, 2012; Mohamed, 2014) investigated the development of teachers' epistemic beliefs without using a prescribed intervention (i.e., a course or professional development). Anderson and Clark (2012) followed a teacher as she designed a unit of instruction and discussed her beliefs throughout. Mohamed (2014) looked at how different factors, both cultural and demographic, might correlate with epistemic beliefs.

13 of the 33 studies occurred in the United States of America (USA). These studies showed a lot of variety in the level of courses teachers taught, the number of participants, and whether they were pre- or in-service teachers. As shown in Table 3, the scholars have published USA studies relatively consistently for the past 25 years. Scholars studying science education in the Middle East have more recently begun publishing about the development of teachers' epistemic beliefs

about science. Since 2011, we identified seven studies investigating the development of teachers' epistemic beliefs were conducted in the Middle East; all seven studies used pre-service teachers but were distributed among teachers training for early, middle, and senior years science. Five studies in this analysis were conducted in Europe, all since 2011. European studies had a range of early, middle, and senior year teachers. Both pre- and in-service teachers participated in these European studies. Canada had three studies represented and Oceana had two studies included. Finally, there was one study included from each of China and Africa.

The number of participants when studying teachers' epistemic belief development varies greatly across studies. The smallest studies focused on one participant (n = 4) with many studies focusing on 10 or fewer teachers (n=11). The largest study was conducted in the Middle East with early years pre-service teachers and had 821 participants (Belet & Guven, 2011). The second largest study was 181 participants by Abd-El-Khalick and Lederman (2000). Removing the largest study of 820 participants—as it was an outlier—gave an average of 35 participants per study.

Interventions

All but two of the studies in this review used some type of intervention in the hopes of impacting the development of teachers' epistemic beliefs. These interventions fell into two categories: university courses and professional development (PD). University courses were typically aimed at explicitly teaching epistemological aspects of science and the areas claimed to impact the development of these beliefs, such as the history of science (e.g., Abd-El-Khalick & Lederman, 2000) and the nature of science (e.g., Belet & Guven, 2021; Erduran & Kaya, 2018), and socio-scientific issues (e.g., Erumit & Yuksel, 2023). Another theme describing the types of interventions within university courses was engaging pre-service teachers with the practices of science such as through a practicum experience (e.g., Anderson et al., 2006) or apprenticeship (e.g., Bencze, 2010).

Similarly, PD experiences also aimed at developing teachers' epistemic beliefs through experiencing the practices of science (e.g., Bencze & Elshof, 2004; Dai, 2022), explicit instruction on the epistemological aspects of science (e.g., Barak et al., 2023; Kurup, 2014), and the epistemological aspects of pedagogical content knowledge (e.g., Anderson & Clarke, 2012; Nilsson, 2014). PD interventions in this review also considered how engagement with ways of instructing science might impact teachers' epistemic beliefs; instructional approaches included inquiry (e.g., Jaber et al., 2021; van Uum et al., 2021) and conceptual change (e.g., Kang, 2007). In general, the interventions aimed at explicitly teaching the epistemological aspects of science (n = 29), engaging teachers with the practices of science (n = 15), and/or considering how exposing teachers to pedagogical strategies in science may change epistemic beliefs (n = 17).

Table 3. Comparison of location by publication year

Location	1999 to 2005	2006 to 2010	2011 to 2015	2016 to 2020	2021 to 2024
USA	2	4	2	1	4
Oceana		1	1		
Middle East			3	2	2
Europe			1	1	3
China					1
Canada	1	2			
Africa			1		

Intervention Duration

Given that most (n = 31) studies used an intervention, we analyzed the duration and nature of these interventions. A summary of the duration, compared to the type of intervention, is included in Table 4. It was most common for interventions to last between three and six months (n=19) with most of these interventions being conducted within university courses (n = 14). No identified studies lasted between 13 and 23 months. One study lasted longer than two years. Dolphin and Tillotson (2015) which followed the development of seven in-service, senior science teachers over three years.

Data Collection

Studies investigating the development of teachers' epistemic beliefs had varied methods of data collection. Findings in this section are described using questionnaires, interviews, submitted work, or observations.

Questionnaires

19 of the 33 analyzed studies used questionnaires in their data collection. Both quantitative and qualitative questionnaires were used to describe and/or identify teachers' epistemic beliefs. 10 studies used quantitative, likert-scale questionnaires. These were most often self-written (n = 6) but also included some epistemic beliefs inventories such as the Epistemological Beliefs Inventory (n=1; (Schraw et al., 2002) and the Epistemological Beliefs Questionnaire (n=3; Hofer & Pintrich, 1997). Quantitative questionnaires were most often collected before and after the study intervention (n = 9). One study (Mohamed, 2014) that did not use an intervention used quantitative questionnaires to collect teachers' perceptions on their epistemic belief development.

Qualitative questionnaires were used by 11 of the 37 studies analyzed. Researchers were varied in which qualitative questionnaires they chose to use to describe and/or identify teachers' epistemic beliefs about science. These included versions of the Views of Nature of Science (VNOS) versions B and C (n=3; developed by Lederman et al., 2002) and a content representation (CoRe) document (developed by Loughran et al., 2006). Many studies (n=7) chose to design their own open-ended questionnaire to capture teachers' epistemic beliefs. Most (n=9) studies using qualitative questionnaires administered these questionnaires before and after the intervention, with one study (Donohue et al., 2020) only administering questionnaires during and after the intervention, and one study (Voss et al., 2023) only administering questionnaires during the intervention.

Interviews

Interviews were the most used data collection method in these studies with 20 studies having some type of interview included. Of these 20 studies, 17 used individual interviews with semi-structured protocol. Semi structured interviews could occur prior to and after the intervention (n = 5), throughout including before and after the intervention (n = 4), during the intervention only (n = 1), during and after the intervention (n = 4), after the intervention only (n = 2). One study did not indicate when their semi-structured interviews took place in relation to their intervention. Four studies in this review used interviews that were not individual nor semi-structured. Two of these studies used structured protocols. Both studies interviewed participants before and after the intervention. One study (Anderson et al., 2006) used focus groups to capture the epistemic beliefs of their teacher participants.

Table 4. Duration of research described by intervention type

Duration of Development	University Course	PD
2 months or less	2	3
3 - 6 months	12	5
7 - 12 months	5	2
> 2 years		1
Total	**19**	**11**

Finally, some studies chose to use both interview and questionnaire data. Three studies used both quantitative questionnaires and semi-structured interviews. Five studies used qualitative questionnaires combined with semi-structured interviews. Only two included studies (Kang, 2007, 2008) did not use questionnaires or interviews in their data collection, focusing instead on submitted work and observations.

Submitted Work

17 studies used some type of submitted work in their data set to analyze the development of teachers' epistemic beliefs. Most (n = 11) studies collected and analyzed participants' written reflections. There were a few (n = 2) studies that used drawn reflections, both analyzing epistemic beliefs from the family-resemblance approach to nature of science (Erduran & Kaya, 2018; Barak et al., 2023). The largest study to use written reflections as a data set had 24 participants. Further, four studies analyzed teaching materials to capture teachers' epistemic beliefs. The largest study to use this type of data was 19 participants.

Another type of submitted work, was what these researchers call student work. This included responses to vignettes (e.g., Veal, 2004) and completed activities and assignments (e.g., Erumit & Yuksel, 2023; Lopez-Banet & Martinex Carmona, 2021; Windschitl et al., 2008). Seven studies analyzed student work. Studies analyzing submitted work ranged in participant numbers but no study with this type of data collection was over 80 participants. Further, no study used only student work to capture teachers' epistemic beliefs about science; studies used questionnaires (n=5), interviews (n=4), and observations (n = 4) to support any conclusions.

Observations

16 of 33 studies used observations as a point of data collection. These observations were typically video or audio-recorded and then coded following the intervention. 14 studies observed participant talk and interactions during the intervention itself. Five studies recorded teaching and coded for epistemic beliefs shown in the teaching, one of which was conducted with pre-service science teachers. Further, of the 16 studies using observation data, 15 also collected interview data and four studies used questionnaires, interviews, submitted work, and observations. Kang (2007) did not collect interview data instead focusing on observation data and submitted work in their analysis.

Findings

Of the 31 studies using interventions, two concluded that their intervention had little or no significant impact on the development of teachers' epistemic beliefs. Investigating the impact of a professional development program on teachers' subject knowledge, one aspect of which was their epistemic subject matter knowledge, van Uum (2021) found no significant improvement in epistemic subject matter knowledge when comparing the treatment and control group. Van Uum et al. hypothesize that this absence of improvement could be attributed to a lack of explicit focus on teaching the NOS. Abd-El-Khalick and Lederman (2000) explain that the inclusion of one history of science course minimally influenced students NOS views, concluding that "one [history of science] course is not likely to enhance students' NOS views in any substantial way," (p. 1085). Despite these findings, Abd-El-Khalick and Lederman went on to explain that this finding is counterintuitive.

The remaining studies, including the two studies that did not use interventions, indicated at least some change in teachers' epistemic beliefs. No study reported change in all participants. 13 studies discussed the changes of teachers' epistemic beliefs in general or overall; these studies did not focus on specific aspects or dimensions of beliefs. For example, McDonald (2010) indicated that four of five teachers' views of NOS developed from predominantly naïve or limited to predominantly partially informed or informed understandings of NOS. Kang (2008) indicated that 35% of the teachers in their study showed more sophisticated epistemologies after field experience and reflection. Organ-Bekiroglu and Arslan-Buyruk (2018) indicated four students

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held naïve epistemologies and one sophisticated epistemology before their intervention and after their intervention only one student held naïve epistemologies. General reporting of belief changes was common in studies.

18 studies reported changes using dimensions or aspects of these beliefs. Belief changes were reported in a variety of ways and dimensions given the variety of frameworks included. To simplify reporting, we have used the framework provided in Table 2 to summarize the changes in beliefs and reproduced this in Table 5. Methods and procedures include changes seen in the empirical nature of science, the role of observations and inferences, shared methods across science, and the roles of peer evaluation and technology in the scientific community. Source includes the role of humans in creating science knowledge, the influence of society and culture, and the creativity involved in science. Certainty includes beliefs about subjectivity and the durable yet tentative nature of science. Structure includes beliefs about the limits of science and the interconnectedness of scientific ideas. Finally, the Ability to Learn describes beliefs about capability in learning science and learning effort describes beliefs about the amount of effort it takes to learn science.

As shown in Table 5, it was most common to see belief change in the source of scientific knowledge. This typically referred to a change in beliefs about science as a human endeavor (e.g., Bencze, 2010; Dai, 2022; Davidson et al., 2022). Studies have found that teachers are often most likely to hold misconceptions in this aspect of epistemic beliefs about science (Watson & Thomas, 2023), so this is unsurprising. There is also promise in changing teachers' epistemic beliefs about the methods and procedures and certainty of science given the number of studies that saw changes in these areas. Few studies reported changes in beliefs about the structure, ability to learn, and learning effort in science but this could be because these areas are not often explicitly discussed in the NOS literature.

Themes Attributed to Change

Across these 33 articles, five themes were identified as contributing factors to the development of teachers' epistemic beliefs: time, explicit instruction, connection to practice, initial beliefs, and reflection and questioning.

Table 5. Epistemic belief dimensions indicated as showing positive growth in studies

Methods & Procedures	Barak et al. (2023); Bencze & Elshof (2004); Davison et al., (2021); Pérez & Díaz-Moreno (2022); Kurup (2014); Mohamed (2014)
Certainty	Deniz (2011); Erumit & Yuksel (2023); Jaber et al. (2021); Ozgelen (2012)
Source	Barak et al. (2023); Bencze (20101); Bencze & Elshof (2004); Dai (2022); Davidson et al. (2022); Deniz (2011); Erduran & Kaya (2018); Jaber et al (2021); McDonald (2010); Mohamed (2014); Ozgelen (2012); Voss et al. (2023)
Structure	Kang (2008)
Ability to Learn	Belet & Guven (2011)
Learning Effort	Belet & Guven (2011)

Time was a possible factor in teachers' epistemic belief development. Mohamed (2014) found that in-service teachers held more mature beliefs in several dimensions than pre-service teachers, claiming that this indicates that teaching experience and time in the teaching field can help develop teachers' beliefs. Further, Belet and Guven (2011), who worked with over 800 pre-service teachers found that students in their third and fourth years of university had more mature beliefs than those in their first and second years. However, Barak (2023) even those participants entering their program with science degrees had low knowledge of the NOS and, consequently, naïve epistemic beliefs. Some studies claimed that those participants with more experience had more mature beliefs, thus, time could be a factor in developing teachers' epistemic beliefs.

Some studies indicated that teachers' epistemic beliefs were more likely to change if they already held more sophisticated beliefs. Abd-El-Khalick and Lederman (2000) found that a history of science course had little impact on pre-service teachers' epistemic beliefs but found that those students who entered this course with appropriate views of the NOS were more likely to leave their course with more enriched views. These authors hypothesized this might be due to the constructive nature of learning and that those with deep rooted misconceptions about the NOS need instruction using frameworks to address these misconceptions. This is supported by the work of Konneman (2018) who found that teachers' epistemic beliefs about evolution could be changed by direct intervention but that teachers' attitudes about these beliefs were reluctant to change. Further, Deniz (2011) found that teachers' epistemic beliefs at the start of the intervention were, to some degree, an indicator of how much their beliefs could mature. Most studies claimed that teachers' epistemic beliefs about science can be developed but that the effectiveness of interventions might depend on teachers' starting beliefs.

Explicit instruction was a common reason attributed to developing teachers' epistemic beliefs. Kurup (2014) found that two of three teachers receiving explicit instruction in the NOS integrated the NOS into their lessons whereas none of the three teachers in the group that did not receive explicit NOS instruction did not integrate the NOS. Pérez & Díaz-Moreno (2022) and McDonald (2010) indicated that their results support the inclusion of explicit instruction in opportunities aimed at improving teachers' epistemic beliefs about science. Dolphin and Tillotson (2015) compared results from three institutions and found that participants from one institution had more developed epistemic beliefs when compared to the other two institutions, which they indicate could be due to that one institution having explicit courses in the NOS. Finally, Voss (2023) taught the first portion of their intervention with NOS pedagogy being implicitly modeled and saw very little change in beliefs. However, Voss et al. saw dramatic increases in participants' knowledge of NOS pedagogy when they began to include explicit related discussions. Explicit instruction was a common focus of interventions, and many found this to further the development of teachers' epistemic beliefs.

Studies also indicated that teachers' epistemic belief development was influenced by the connections they perceived to practice. Lopez-Banet and Martinez-Carmona (2021) found that teachers' beliefs changed in 13 areas focused on teaching and learning chemistry but that those areas focused on teaching practice saw the greatest increase. According to Dai (2022), belief change was mitigated by whether teachers saw the professional development as useful to their practice. Specifically, studies found inquiry-based teaching to support belief development. Ozgelen (2012) found that inquiry-based and explicit-reflective NOS instruction improved pre-service teachers' beliefs about the certainty and source of scientific knowledge. According to Pérez & Díaz-Moreno (2022), explicit NOS instruction coupled with inquiry-based experiences helped develop participants' beliefs about teaching science. Along with explicit instruction, teachers' perception of the usefulness of epistemic belief interventions

Finally, epistemic belief change was often attributed to the challenging of one's beliefs and the use of explicit reflection. In a self-study, Donohue (2020) found that change resulted from having beliefs challenged. As this teacher worked to understand their beliefs, challenges prompted exploration which eventually led to change. Studies (Bencze & Elshof, 2004; Davidson et al., 2022; Mohamed, 2014) indicated that teachers attributed belief change to the use of critical events and epistemological probes designed to challenge teachers' beliefs followed by a period of reflection. For Donohue et al.'s (2020) single participant, change came because of having their beliefs challenged. As Nilsson (2014) highlighted, these types of interventions could spark belief development since they helped teachers begin to question their epistemic beliefs. According to this review, time, explicit instruction, connection to practice, initial beliefs, and reflection and questioning are all contributing factors to teachers' epistemic belief development.

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DISCUSSION AND CONCLUSION

Over the last 25 years, research has investigated the development of teachers' epistemic beliefs in a variety of contexts and using several methods. 33 studies were identified in this systematic literature review. The development of teachers' epistemic beliefs has been studied with varying population sizes (from n = 1 to n = 821), in a variety of countries, with both pre- and in-service teachers, and with teachers of elementary, middle, and high school students. Commonly, interventions such as university courses and professional development experiences were used to support the development of teachers' epistemic beliefs. Further, a variety of methods have been used in studying teachers' epistemic beliefs with (qualitative and quantitative) questionnaires, semi-structured interviews, observations, and reflections. It was common for studies to use multiple methods to triangulate and support any conclusions.

The development of epistemic beliefs has been of growing interest to science education researchers over the last 25 years, but the research in considering the development of teachers' beliefs, according to our findings, has been comparatively limited. We identified only 33 studies of approximately 700 that considered teachers' epistemic belief development and of these 33 studies, 31 studies analyzed the impact of a relatively short intervention; interventions lasted from less than 2 months to slightly over 2 years, with 23 of these studies having interventions lasting 6 months or less. Belief change is a process that takes time; to reflect this, we call on researchers in the field to consider how we might research the development of teachers' epistemic beliefs over a longer duration.

Even with this relatively small sample of articles on the topic of teachers' epistemic belief, there is a varied understanding of how we, as a field, conceptualize this construct, but there is a preference to use the NOS. A majority of articles in this review used the NOS to conceptualize what we call epistemic beliefs. Under the NOS, both the consensus and family resemblance approach were used to describe epistemic beliefs. Most often, the NOS was used to describe teachers' knowledge (Erduran & Kaya, 2018; Pérez & Díaz-Moreno, 2022; van Uum et al., 2021), views (Abd-El-Khalick & Lederman, 2000; McDonald, 2010), and understanding (Anderson & Clark, 2012; Donohue et al., 2020; Kurup, 2014; Niaz, 2008); a very cognitive approach to beliefs. Our findings reify the message from Stroupe (2025), that the NOS dominates the epistemic discussion in science education.

As highlighted by Stroupe (2025), this domination of NOS is problematic. First, the NOS perpetuates a hegemonic structure in science education; only those who play within the power structures in place (i.e., publishing about the NOS) can have their voice heard when discussing the epistemic aspects of science. This would explain why we found very few articles published about epistemic beliefs in science education literature space that did not use the NOS as an organizing construct. Further, in the most cited articles in their review, "teachers were described as lacking knowledge about NOS, which [they] interpreted to mean [these teachers] were ignorant about how science knowledge is constructed, and, thus not fully qualified to teach science," (Stroupe et al., 2025, p. 926). Our findings concur as most NOS studies were also interventions, intended to improve teachers' epistemic knowledge, implying that they started the intervention at a deficit. The prevalence of the use of NOS as a conceptualization of epistemic beliefs is worthy of consideration of the field; does the NOS represent an agreed upon framework to use when describing belief development?

Beyond the NOS, studies also used multi-dimensional epistemic beliefs models, considering dimensions commonly used in the field such as the attainability of truth by, certainty of, justification/source of, and structure of scientific knowledge. Two studies also included learning in their conceptualization of epistemic beliefs. Despite these studies considering the development of teachers' epistemic beliefs, epistemic belief development models were not well represented with only one study using this approach. We suggest that the field consider how we might more often integrate models of epistemic belief development with those conceptualizations presented in these studies such as was shown in Feucht (2017).

Most (n=31) studies indicated at least some development in teachers' epistemic beliefs; two studies found little or no significant impact of interventions on the development of teachers' epistemic beliefs. Five themes arose from analyzing the findings from the 33 included articles. As has been long known in the epistemic belief development literature (see Perry, 1970; Hofer & Pintrich, 1997), time can contribute to the development of epistemic beliefs, and this was corroborated by the analyzed studies in this systematic literature review. We hypothesize that focused experiences and developmental opportunities are likely included in this factor as time alone may not be the indicative factor but were not discussed in these studies. Further, as has been discussed in literature investigating students' epistemic belief development (Baytelman et al., 2020; Khishfe, 2014, 2021), explicit instruction was found to facilitate the development of teachers' epistemic beliefs. A unique aspect to teachers' epistemic belief development, when compared to the general field of epistemic beliefs about science, is that teachers' belief development was influenced by the connections of interventions to practice; if teachers saw the experience as something connected to their teaching practice, their beliefs were more likely to mature. Epistemic belief change was also found to be facilitated by providing experiences that challenge one's beliefs and using explicit reflection to support working through this challenge. Similar to the findings of Murphy & Alexander (2016) with students, teachers' epistemic belief development was facilitated by confronting the misconception (or naïve beliefs). To continue to push this field forward, we suggest researchers consider exploring the longer-term impacts of these factors and how teachers perceive these factors influence the development of their beliefs.

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