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ARTICLE

Drawing a Portrayal of Science Teachers' Epistemic Cognitions Around Different Concepts Characterizing Science Education

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Abstract
The objective of this descriptive study is to provide a detailed examination of science teachers' perspectives regarding scientific knowledge, science learning, science concepts, and science teaching. A total of 304 science teachers created metaphors to express their cognitions about the epistemological aspects of their work. A specifically designed metaphor construction task was used to capture the participants' epistemic cognitions. The participants' metaphorical reasoning was captured since the metaphors might deliver experience-based conceptions, perceptions, beliefs, or comprehensions about four concepts regarding epistemic cognition. In-depth, descriptive analysis was undertaken through open, axial, and selective coding procedures with higher validity and reliability. The participants' epistemic cognitions were gathered around five-order themes: function (accepting science knowledge and science concepts and their teaching/learning as vital entities by adopting an instrumentalist or tool-based perspective), personal epistemological stance (seeing science knowledge and science learning as an endless and immortal accumulation of factual knowledge), motivational construct (scientific knowledge attaches importance so it should be taught in the school systems in the science lessons), sociological construct (science knowledge provides power), and pedagogical construct (not the science knowledge but the science concepts should be taught in the schools in the science lesson). This study concluded that the participant science teachers mostly held conventional orientations in externalizing their epistemic cognitions. Theory-based explanations are presented in terms of the participants' traditional epistemic orientations in the sense of future directions of further research.

1 Introduction

The objective of the present study is to provide a detailed examination of science teachers' perspectives regarding "scientific knowledge," "science learning," "science concepts," and "science teaching." It is well acknowledged that once science teachers identify their perspectives via verbal expressions around the four concepts listed above, they

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may externalize their epistemic cognitions (Suh et al., 2022). However, what is epistemic cognition, or how should this term be contextualized under the present research?

Epistemic cognition (Greene et al., 2010; Hofer, 2016) explores how individuals think about knowledge, employing specific questions to delve into their cognitive processes. These inquiries encompass various aspects, including people's perspectives on what others know, such as science concepts and theories generated through specific methodic techniques, instruments, thinking styles, reasoning, and communication (Greene et al., 2010). Furthermore, epistemic cognition investigates the nature of knowledge, encompassing scientific knowledge, science concepts, formulas, principles, and models, its generation process, and the historical, philosophical, sociological, and institutional factors that shape it (Hofer, 2016). Additionally, this field explores how knowledge can be utilized for epistemological purposes, such as making meaning of natural and social phenomena, explaining unexpected events, and enhancing daily life (Sandoval et al., 2016). It also examines individuals' understanding of their knowledge, including thinking about thinking, thinking about knowing, thinking about cognitive processing, and metacognitive epistemic cognition (Sandoval et al., 2016).

As an important note, "nature of science" (NOS) research and "epistemic cognition" research are related but distinct areas of study within the field of science education and psychology. NOS research involves understanding and characterizing science's fundamental nature and characteristics. It seeks to identify the key features, principles, and processes that define science as a way of knowing (Abd-El-Khalick & Lederman, 2000; Irzik & Nola, 2023). Epistemic cognition research studies individuals' thinking about knowledge and knowing. It delves into how people conceptualize knowledge, assess the credibility of information, and understand the nature of truth and justification (Greene et al., 2010; Hofer, 2016).

The terminology surrounding epistemic cognitions can be confusing, as scholars have used various terms interchangeably. For instance, terms like epistemic beliefs, epistemological beliefs, epistemic development, personal epistemologies, and personal epistemic beliefs have all been used to describe similar concepts. Indeed, epistemic cognition defines generic, more holistic mental perspectives (e.g., an interrelated network of mental models or cognitive schemes) of humans. This term may consider and incorporate different perspectives of practice while building mental schemes such as *science learning* or *science teaching*. However, the other terms listed above, such as personal epistemic beliefs or personal epistemologies, may define a more subjective orientation in identifying what knowledge is and how that knowledge is validated. Therefore, this study employs epistemic cognition to examine the science teachers' perspectives regarding their epistemic beliefs, including teaching and learning practices. This refers to how individuals develop and interpret knowledge (e.g., science knowledge and science concepts) and the process of knowing (e.g., science learning and science teaching) (Sandoval et al., 2016), including learning and teaching (Suh et al., 2022). In the present study, the term epistemic cognition encompasses three fundamental constructs related to individuals' understanding of epistemology: the nature of knowledge (e.g., science knowledge and science concepts), the nature of knowing (e.g., science learning), and the nature of learning (e.g., science teaching) (Suh et al., 2022). These constructs are qualitatively investigated in this study through science teachers' perspectives and were not examined in isolation with science teachers' work: science teaching and science learning. In this manner, Chinn et al. (2011) proposed an interconnected definition of epistemic cognition encompassing multiple components, including knowledge (e.g., science knowledge), sources of knowledge, justification, beliefs, evidence-based thinking, truth, and acquiring (e.g., science learning), and explaining knowledge (e.g., science teaching).

Initially, research on epistemic cognition focused on individuals' perspectives on epistemology within formal contexts. Kitchener (1983) introduced specific terms to describe how individuals view epistemology, such as laypersons' folk theories of knowledge, knowing common-sense epistemologies, and unquestioned theories of epistemologies. These labels highlight that epistemological cognitions are not limited to formal settings but can also arise in informal contexts. The current study accepted that participatory teachers might construct their epistemic cognitions in formal and informal settings. Out of school, they inherently engaged in epistemic practices such as experiencing various aspects of science knowledge and science learning while traveling by high-speed train because they may think that the reliability of the high-speed train's movement is related to the expansion law of metals when heated. In the school setting, science teachers must ponder the nature of science knowledge (or concepts such as the expansion law of metals when heated) and how it should be taught to students. These are conscious or unconscious epistemological-pedagogical interrogations of science teachers in the formalized schooling systems. In other words, science teachers reflect on the nature of knowledge, how knowledge is acquired in the classroom, and how students grasp scientific concepts and practices during science lessons. Therefore, the present study acknowledges that science teachers can interpret the development of epistemic understanding, dispositions, and conceptions in both formal and informal contexts.

As a whole, epistemic cognition, viewed as an implicit construct (Sandoval et al., 2016), can be understood as a combination of beliefs, dispositions, and skills to determine what one should believe, doubt, or distrust. It explains what, why, and how individuals form beliefs, acquire knowledge, and understand various subjects (Sandoval et al., 2016). In the present study, the epistemic cognitions of science teachers are explored, focusing on three overarching indicators: their verbalizations and conceptualizations regarding the nature of knowledge, the nature of knowing, and the nature of teaching and learning in science lessons. These indicators are the primary qualifications for examining the science teachers' epistemic cognitions. Based on these premises, the current study addresses the following research questions:

> Research Question 1: What is the range of conceptual diversity in science teachers' understanding of four concepts related to epistemological understanding, namely scientific knowledge, science learning, science concepts, and science teaching?
> Research Question 2: What are the associations and reciprocal interactions between science teachers' conceptual articulations regarding the four concepts of epistemological understanding?

1.1 *Justification for the Study*

The findings from previous systematic reviews underscore the valuable role of teachers' explicit reflections as a powerful tool for comprehending and enhancing their epistemic cognitions (e.g., Brownlee et al., 2017). This highlights the significance of actively involving science teachers in reflection-based metacognitive activities that specifically target their epistemological perspectives, as suggested by Kitchener (1983). Science teachers are encouraged to engage in reflective verbalizations by participating in such activities, drawing upon their firsthand experiences. This process, in turn, can potentially enrich their understanding of epistemic cognition (Brownlee et al., 2017). Metacognitive thinking, as outlined by Cottone et al. (2023), involves a multifaceted approach to reflecting on and analyzing one's thinking processes. This includes exercising control over cognitive or epistemic mental models, conducting evaluations, monitoring thought processes, and making judgments. The metacognitive activities proposed by Kitchener (1983) and supported by subsequent research provide a structured framework for science teachers to delve into their thinking patterns, such as the nature of knowledge as a part of their epistemic cognition. Kitchener (1983) initially proposed the crucial concept of capturing reflections on various aspects of knowledge, including its limitations, certainty, and criteria. This proposal is foundational for understanding and developing epistemic cognition, emphasizing the necessity of a deliberate and systematic approach to reflecting on the nature of one's knowledge. By engaging in reflective practices encompassing these dimensions, science teachers can gain a deeper insight into their epistemic cognitions and actively contribute to their ongoing development and refinement.

The present study examined the science teachers' understanding of knowledge and acquisition, focusing on four aspects: *scientific knowledge* (epistemologically stimulating questions: What is scientific knowledge for me? What does science offer me? What is the content of science in terms of knowledge?), *science concepts* (epistemologically stimulating questions: What do I teach children at school? What do these teachings, such as scientific concepts, mean to me? What is the nature of what I teach? Is what I teach scientific knowledge?), *science learning* (epistemologically stimulating questions: How do I acquire scientific knowledge? What does learning scientific knowledge mean to me? Is there a relationship between the nature of what I am learning and how I learned it? What does what I learned as scientific knowledge mean to me?), and *science teaching* (epistemologically stimulating questions: How do I teach at school? Is what I learned different from what I teach? What are the things I taught in school?). These strands encompass epistemological perspectives on knowledge and pedagogical considerations (Sandoval et al., 2016). The investigation took place at the psychological level, delving into individuals' reflections and beliefs about the nature of knowledge (Hofer & Pintrich, 1997; Perry, 1968). When contemplating scientific knowledge and science concepts, participants had to articulate their epistemological theories as they defined knowledge. Moreover, their verbalizations on science learning and science teaching revealed an integration of epistemologically oriented pedagogical beliefs (Schommer, 1990), capturing their perspectives on the process of knowing and how knowledge is acquired (Hofer & Pintrich, 1997).

Within the existing literature, two paradigms characterize science teachers' epistemological orientations: *epistemic beliefs* and *epistemic cognitions* (Chinn et al., 2011). While these terms are related, some scholars argue against directly linking epistemic cognition to beliefs about pedagogy, such as teaching and learning science in the classroom (Hofer & Pintrich, 1997). Indeed, epistemic cognition encompasses a broad range of psychologically driven cognitive processes related to the nature of knowledge and knowing. It involves how people reason, perceive, and make decisions about knowledge. Epistemic cognition is context-dependent and situational, incorporating diverse thinking and communication systems regarding the nature of knowledge (Chinn et al., 2014). On the other hand, epistemic beliefs refer specifically to individuals' beliefs about the nature of knowledge and learning. Epistemic beliefs focus on personal convictions about certainty, simplicity, and source of knowledge (Tanase and Wang, 2010). They are more specific and reflective of an individual's overall stance on knowledge and learning. Epistemic cognition incorporates more sub-elements, including reasoning, perception, decision-making, and understanding knowledge dynamics in various contexts.

It is more comprehensive, involving cognitive activities that influence how individuals interact with and understand knowledge (Hofer, 2016). However, epistemic beliefs typically include beliefs about the certainty of knowledge (e.g., whether knowledge is certain or uncertain), the simplicity of knowledge structures (e.g., whether knowledge is simple or complex), and the source of knowledge (e.g., whether knowledge comes from authority or personal experience). More importantly, epistemic cognition recognizes knowledge-related cognitive processes' context-dependent and situational nature. It acknowledges that individuals may employ different cognitive strategies in various situations (Hofer, 2016). Like other belief systems, epistemic beliefs tend to represent more stable and overarching convictions about the nature of knowledge. While they can evolve, epistemic beliefs are often seen as relatively enduring aspects of an individual's belief system. As the main argument of the present study, epistemic cognition can be explicitly linked to cognitive processes that influence how individuals engage with educational content, make sense of information, and participate in learning activities. It has a broader connection to pedagogical practices (Maggioni & Parkinson, 2008). On the other hand, epistemic beliefs may often be studied in the context of their influence on learning and instructional preferences. For example, an individual with strong epistemic beliefs favoring certainty might prefer a more traditional, authority-driven approach to teaching. In summary, while epistemic cognition and beliefs revolve around understanding knowledge, epistemic cognition is a broader concept encompassing various cognitive processes. In contrast, epistemic beliefs are more specific, focusing on personal convictions about the nature of knowledge and learning (Maggioni & Parkinson, 2008).

Scholars caution against directly linking epistemic cognition to beliefs about pedagogy due to the multifaceted nature of epistemic cognition, its context dependence, the diverse influences on pedagogical beliefs, the developmental nature of both constructs, and the conceptual and methodological challenges associated with studying them (Greene et al., 2010; Hofer, 2016; Sandoval et al., 2016; Suh et al., 2022). In essence, while epistemic cognition and beliefs about pedagogy may intersect and influence each other to some extent, scholars caution against oversimplifying the relationship (Greene et al., 2010; Hofer, 2016). They emphasize the multidimensional nature of both constructs and the need to consider broader factors contributing to teachers' beliefs and practices in teaching and learning (Greene et al., 2010; Hofer, 2016). Recognizing the complexity of these constructs allows for a more nuanced understanding of the intricate interplay between cognitive processes and pedagogical beliefs in the educational context (Sandoval et al., 2016). Thus, science teachers' epistemic cognition cannot be thought of in isolation from learning and teaching and the contents, what-aspects (e.g., nature of science knowledge, structure of science concepts), and how-aspects (e.g., methodological thinking tools to construct canonical science knowledge) of these contents taught in the science lessons. It is essential to connect science teachers' understanding of the nature of knowledge and knowing to their perceptions of how individuals acquire knowledge (Suh et al., 2022). As a comprehensive term, epistemic cognition encompasses various psychologically driven cognitive processes concerning the nature of knowledge and knowing, including reasoning, perception, and decision-making (Greene et al., 2016). Epistemic cognition is fundamentally context-dependent and situational, as science teachers utilize their epistemic cognitions to comprehend the nature of knowledge. It can be seen as an epistemic toolkit encompassing diverse thinking and communication systems regarding the nature of knowledge and knowing. This can be observed during specific moments of in-class science classroom discourse (Maggioni & Parkinson, 2008). Therefore, the present study expands the concept of epistemic cognition by delving deeply into science teachers' reasoning about the abovementioned four concepts, considering their extensive experiences with these concepts in their science lessons and beyond the classroom setting.

The present study argues that underlying interrelationships or reciprocal determinisms (Suh et al., 2022) may exist among teachers' conceptions of scientific knowledge, science learning, science concepts, and science teaching. According to Suh et al. (2022), there is a connection between epistemic paradigms and (science) teaching. They suggest that science teachers possess belief-related sources that incorporate their deeply rooted notions about the nature of knowledge, knowing, learning, and teaching. These sources shape their epistemic orientations, manifesting as either epistemologically oriented or pedagogically oriented systems of beliefs. A teacher's epistemic orientation influences their focus on a particular learning environment. It serves as a guiding force, directing their cognitive processes as they engage with knowledge and participate in knowledge development. This process involves navigating diverse epistemic resources (Suh et al., 2022). By comprehensively examining science teachers' various epistemological and pedagogical mental resources, the field can advance its understanding of their complex interconnectedness, acknowledged as an unexplored domain within science education (Brownlee et al., 2017; Park et al., 2022; Suh et al., 2022).

2 Theoretical Background

Science teachers' epistemic cognitions can be explored through developmental and dimensional approaches. Developmental models propose that individuals progress through stages of belief sophistication regarding knowledge and knowing. Dimensional models suggest that individuals can hold diverse personal theories about knowledge and knowing regardless of their stage or phase. Despite their differences, these approaches exhibit significant consistency and overlap.

Perry (1968) proposed that in the initial stage of his model, dualists perceive social or natural phenomena as objective entities independent of interpretation, leading to a belief in knowledge as factual, complete, and perfect. This perspective aligns with the certainty of knowledge often portrayed in the science education literature, where science teachers see knowledge as a stable, static, and unchanging entity (Bahcivan, 2019; Bahcivan et al., 2019). Dualists argue that scientific knowledge is stable and exclusive to specific groups of researchers. Consequently, for dualists, acquiring knowledge involves borrowing it from individuals with expertise in a particular field. In teaching and learning science, knowledge is perceived as an external entity that can only be replicated by others. However, the dualist stage is counterproductive to critical thinking and reflection in science education (Cheng et al., 2010). Another stage in Perry's model characterizes multiplistic individuals who believe that knowledge is subjective and can vary from person to person, reflecting a solid subjectivity in understanding the nature of knowledge and knowing. In the further stage of relativism, Perry (1968) describes how individuals perceive knowledge as situated and contextually embedded. Consequently, they employ critical judgment and rely on logic and reasoning to distinguish essential and relevant propositions from irrelevant or unnecessary ones. The fourth phase, commitment within relativism or committed relativists, involves individuals actively seeking to construct identities to regulate their reasoning about knowledge and knowing.

Kuhn's (2001) model of epistemic stages reveals similar developmental categories (Kuhn et al., 2000). Kuhn (2001) focused on informal reasoning scenarios where participants engaged with everyday issues, leading to the identification of developmental stages. These stages revolve around the objectivity and subjectivity of knowledge and knowing. For instance, absolutists believe that expert opinions represent factual knowledge capable of accurately describing natural phenomena. They perceive knowledge as certain and the final product of objective reality-seeking processes. In science education, this stage is closely associated with notions of certainty and the sources of knowledge. Science teachers may adopt an epistemic orientation that views scientific knowledge or science concepts as fixed structures obtainable from external resources (Chan, 2011). In Kuhn's model, absolutists and multiplists believe that critical judgments regarding the nature of knowledge and knowing are not essential. For instance, multiplists argue that reality, as the manifestation of ultimate truth, cannot be fully understood due to the subjective nature of the human mind and its information processing. This implies that truth or knowledge encompasses a personal orientation, according to the perspective of multiplists.

Regarding the construction of scientific knowledge, this stage is closely linked to the justification of knowing. It suggests that science teachers may hold personalized and private knowledge claims that do not necessarily require a solid or rigorous justification (Sengul et al., 2020). On the other hand, evaluativist science teachers demonstrate a tendency to employ critical judgments and thinking when selecting propositions. They prioritize propositions that can be presented in a warranted manner or through justified reasoning. While evaluativists share a common perspective with multiplists, acknowledging the subjective nature of knowledge and knowing due to the information-processing characteristics of the human mind, they also emphasize that a knowledge claim gains credibility and reliability when it is more justifiable than alternative claims. Consequently, in science education, it was observed that evaluativists science teachers strive for a more rigorous process of generating warranted arguments to justify knowing (Topcu, 2013).

In a distinct approach, Schommer (1990) presented a model that offers an alternative perspective on the epistemic cognitions of science teachers. In Schommer's dimensional model, she attributed epistemic cognitions' individual-led and independent nature. This model suggests that individuals can exhibit various aspects of epistemological understanding, irrespective of stage-like hierarchies. According to Schommer's model, individuals can differ in the sophistication of their epistemic accounts, ranging from naïve to complex. However, this sophistication does not necessarily imply a developmental or phase-based orientation. Schommer-Aikins (2004) introduced a model of five dimensions of epistemic beliefs: simple knowledge, certain knowledge, source of knowledge, ability to learn, and quick learning. However, some of these dimensions in Schommer's model do not directly pertain to epistemological orientations. For example, the dimensions of ability to learn and quick learning are considered beliefs about learning rather than epistemic cognitions. Fixed ability primarily relates to science teachers' understanding of intelligence, whereas they may view intelligence as a predetermined or fixed entity or something that can be enhanced (Suh et al., 2022). Quick learning reflects an individual's perception of learning.

On the one hand, science teachers may believe science learning should occur rapidly to acquire scientific content and practices effectively (Suh et al., 2022). On the other hand, science teachers may think that learning takes time and happens gradually (Guven et al., 2014). The dimension of simple knowledge, as a more epistemically oriented aspect in the model, pertains to one's understanding of the nature of knowledge. Science teachers may perceive knowledge as discrete pieces accumulating or forming a pool (Guven et al., 2014). However, they may also conceptualize knowledge as an interconnected web of interrelated pieces of information (Morales, 2016). Additionally, the dimension of certain knowledge addresses individuals' epistemic orientations. Within this dimension, science teachers can either believe that knowledge is fixed, absolute, and unchanging (Apostolou and Koulaidis, 2010) or perceive knowledge as evolving and tentative, subject to new evidence, explanations, and thinking systems (Koyunlu Unlu and Dokme, 2017).

Hofer and Pintrich (1997) proposed a model based on Schommer's epistemic cognition framework, adopting a dimensional approach. They focused on individuals' beliefs or systems of beliefs concerning the nature of knowledge and the nature of knowing. Both aspects were divided into two sub-components to represent the dimensionality of epistemic cognition gradually. Firstly, within the scope of the nature of knowledge, science teachers may possess an epistemic understanding regarding the certainty of knowledge, viewing knowledge as static and unchanging, unaffected by new evidence or methodological thinking tools (Ozturk & Yilmaz-Tuzun, 2017). Secondly, within another dimension, science teachers may embrace the idea that knowledge is tentative and evolving (Sengul et al., 2020; Topcu, 2013). The second aspect of the nature of knowing is the simplicity of knowledge. Relevant literature has indicated that science teachers may perceive knowledge in two ways: as a cumulative entity consisting of isolated parts or as an interdisciplinary and multidisciplinary entity (e.g., Tanase and Wang, 2010).

Regarding the nature of knowing or learning, the model proposed by Hofer and Pintrich (1997) includes the source of knowledge, representing a dimension where individuals may believe that knowledge is external to them and must be acquired from external sources. In the context of science education, in terms of the source of knowledge, science teachers may believe that knowledge is an external entity that needs to be obtained or borrowed from experts, scientists, or individuals with more excellent knowledge in society (Sengul et al., 2020; Topcu, 2013). In another dimension of the source of knowledge, science teachers may perceive knowledge as a process-based end product resulting from social negotiations of meanings among individuals who hold alternative or competing theories on a given topic (Apostolou and Koulaidis, 2010). Moving on, within the framework of the source of knowledge, the aspect of justification for knowing encompasses epistemic belief orientations. On the one hand, science teachers may believe that knowledge claims are warranted through simple observations or the approval of experts (Bahcivan, 2019; Bahcivan et al., 2019). Additionally, science teachers may believe that justification for knowing can be achieved through intuitive reasoning, where they rely on their "gut feeling" to determine what is correct and why in a specific context (Ozturk and Yilmaz-Tuzun, 2017). Within another dimension, science teachers may experience and express that justified knowledge claims can be generated by employing appropriate exploration instruments and engaging in critical yet constructive evaluation and integration of diverse sources of data and evidence (Bahcivan, 2019; Bahcivan et al., 2019).

The above-synthesized models discussed different models for exploring science teachers' beliefs about knowledge and knowing. Perry's developmental approach and Kuhn's model propose stages in belief sophistication, emphasizing critical thinking. Schommer's dimensional model suggests varied epistemic understandings without strict hierarchy. Hofer and Pintrich adopt a dimensional approach focusing on beliefs about the nature of knowledge and knowing, highlighting dimensions like certainty, simplicity, source of knowledge, and justification for knowing. These models showcase diverse perspectives on science teachers' conceptualizations, underscoring the importance of critical thinking in science education. Therefore, conceptual backgrounds on people's epistemic cognitions embedded in these models are instrumental and illuminating in extracting the participatory teachers' epistemic cognitions around four concepts: scientific knowledge, science concepts, science learning, and science teaching.

3 Significance of the Present Study

Considering those developmental and dimensional models in the context of school science, dimensional models are generally preferred over developmental models. According to Mason (2016), four-dimensional models (e.g., Hofer & Pintrich, 1997; Schommer, 1990) play a crucial role in shaping the perspectives of educational researchers by highlighting the connections between epistemic beliefs and their impact on meaningful science learning. These models also contribute to understanding the influence of instructional interventions on teachers and learners. However, recent studies suggest that these models must be enhanced by posing specific questions to grasp the complexity of science teachers' epistemic cognitions.

In a recent theoretical model proposed by Suh et al., (2022, p. 1657), four elements are introduced to characterize science teachers' epistemic cognitions. These elements include the following:

(I) General epistemological beliefs derived from previous dimensional models (e.g., the certainty of knowledge, the structure of knowledge, source of knowing, etc.)
(II) Epistemological beliefs specifically related to science (e.g., the openness of scientific knowledge to revision, production of scientific knowledge through methodic approaches like scientific exploration, considering science as a way of knowing to understand the material universe, etc.)
(III) Beliefs about learning (e.g., approaches to learning, learning ability, learning speed).
(IV) Beliefs about teaching (e.g., teaching methods, teacher's role, teaching goals).

Moreover, Suh et al. (2022) raise the question of whether their model or previous models should incorporate additional aspects, which they express by including the question "more?" (p. 1657) in their model. This suggests that by thoroughly examining science teachers' qualitative records based on their experiential and metaphorical understanding of scientific knowledge, science learning, science concepts, and science teaching, a more comprehensive depiction of science teachers' epistemic cognitions can be established, which might not be adequately captured by existing models. The current study explores the intricate relationships and reciprocal interactions between science teachers' perspectives concerning these four conceptions (e.g., scientific knowledge, science concepts, science learning, and science teaching). Thus, the present study has the potential to advance the field by shedding light on how these four aspects of science teachers' epistemic cognitions intertwine with each other.

4 Methods

4.1 Research Design

This descriptive study aimed to capture the epistemic cognitions of science teachers regarding different concepts (scientific knowledge, science learning, science concepts, and science teaching) in their profession. Descriptive studies allow researchers to identify patterns, trends, and relationships within the data (Fraenkel et al., 2012). In this study, the first step was to examine the trends in the data, such as the range of conceptual diversity in science teachers' understanding of the four concepts. Subsequently, patterns and relationships among science teachers' conceptual articulations were identified. This descriptive study aimed to explore new or unfamiliar epistemic understandings of science teachers related to the abovementioned concepts to generate hypotheses for future research.

In this descriptive study, the participants were asked to create metaphors (Lakoff & Johnson, 1980) to express their cognitions about the epistemological aspects of their work (e.g., scientific knowledge, science concepts, science learning, and science teaching). Metaphors serve as socio-linguistic tools, enabling individuals to externalize complex ideas about intricate concepts based on their experiences. When constructing metaphors for the concepts examined in this study, the science teachers had to draw connections between seemingly unrelated ideas based on their subjective experiences, thoughts, feelings, or perceptions (Buaraphan, 2011). Given that the four concepts investigated are tacit cognitive mental models influenced by various context-dependent factors, employing the participants' metaphors as an extracting tool proved valuable as it allowed researchers to access participants' implicit or subconscious understanding through the metaphors they provided (Buaraphan, 2011). Metaphors often tap into deeply rooted beliefs, values, and cultural associations, which are crucial for capturing the authentic epistemic cognitions of the participants concerning the four concepts (Buaraphan, 2011).

4.2 Participants

A total of 304 elementary and middle school science teachers participated in the study, with 197 females (64.8%) and 107 males (35.2%). These participants were selected from various small and large cities in Türkiye, primarily İstanbul (the largest city in terms of population density) with 199 participants (65.46%) and Ankara (the capital city) with 53 participants (17.43%). The participant teachers held different educational degrees, with 189 having undergraduate degrees (62.2%), 111 having graduate degrees (36.5%), and 4 having doctoral degrees (1.3%). They were employed in state-based schools (158 participants, 52%) and private schools (146 participants, 48%). A purposive sampling strategy invited teachers who met specific criteria to participate in the study. One criterion was a minimum of 10 years of teaching experience, with 213 participants (70.1%) having 10–20 years of experience, 59 participants (19.4%) having 21–30 years of experience, and 32 participants (10.5%) having 31 or more years of experience. This variation in teaching experience was expected to contribute to diverse metaphorical reasoning related to the four investigated concepts from the different classroom or extracurricular situations. Only elementary and middle school science teachers who graduated from a faculty of education were included, as secondary school teachers in the Turkish context may graduate from various departments in the faculties of science and literature, such as physics, mathematics, biological sciences, or chemistry. Additionally, participants were required to be engaged in at least one teacher training or professional development program to enhance their in-class teaching strategies. This criterion aimed to gather in-depth and relevant information, particularly when teachers were asked to generate metaphors for science concepts and teaching. Engaging in a professional development or training program becomes justified when considering the potential for science teachers to negotiate and expand their initial or existing beliefs, such as those related to how students scientifically learn science concepts in the classroom. Participation in such professional experiences can contribute significantly to developing science teachers' instructional visions and their ability to notice nuances around the four concepts examined in the present study.

4.3 Data Gathering

A metaphor construction task (MCT, appendix) was developed to capture detailed verbal accounts of the participants' experiences. The task prompted participants to generate metaphors that resonated with their experiences by asking specific questions like "How would you describe [the concept] using a metaphor?" or "Can you think of a metaphor that represents your experience of [the concept]?" The MCT also included an explanation or justification section, requiring participants to explain their metaphors. In other words, science teachers had to verbally externalize their unique perspectives, personal narratives, and underlying conceptualizations after choosing a metaphor for a concept. Based on personal experiences and individualistic viewpoints, these narrative sections might not be easily conveyed through literal language. In this regard, Shuell emphasized, "If a picture is worth 1000 words, a metaphor is worth 1000 pictures! For a picture provides only a static image while a metaphor provides a conceptual framework for thinking about something." (Shuell, 1990 p. 102). In this regard, Shuell (1990) underscored the power of metaphors by suggesting that while a picture may convey many details and information, a metaphor surpasses it in value. While a picture offers a static representation, a metaphor goes beyond by providing a dynamic conceptual framework that stimulates thoughtful consideration and a deeper understanding of a subject or idea (e.g., scientific knowledge, science concepts, science learning, science teaching). It implies that the richness and depth of meaning encapsulated in a metaphor exceed the informational capacity of even a thousand pictures. Therefore, the MCT was used as a data-gathering tool to capture diverse layers of the participants' epistemic cognitions in the current study.

Each participant was required to generate four metaphorical reasonings using the MCT. This task proved challenging for participants as it was their first time utilizing metaphorical thinking to express their comprehension of complex concepts like scientific knowledge. While science teachers may unconsciously employ metaphors daily, the current study demanded that they intentionally create metaphors for specific concepts. The pilot study, which involved 43 science teachers as initial participants, revealed the importance of establishing authentic metaphors to articulate their epistemic understanding of the four concepts. Consequently, more explicit instructions were developed to assist participants in constructing their metaphors. An introductory video was prepared and shared with the participants, outlining the study's objectives and potential benefits for the professional development of science teachers. The MCT was thoroughly explained within the 4-min video, sample completed MCTs were presented and interpreted, and metaphor examples were provided. However, the example metaphors were sourced from various domains to avoid influencing the participants' original metaphorical reasoning. The content of the video underwent review by external experts and was revised based on their suggestions. For instance, two experts recommended adopting more informal language to establish a comfortable and effective means of communication with potential participants.

Data were collected using face-to-face interactions with physical forms and online platforms with digital records. As previously mentioned, the data collection process spanned 28 months to ensure access to potential participants selected with a specific purpose. Initially, a video and MCT were emailed to 1003 elementary and middle school science teachers. Out of the total, 519 teachers responded and were provided with additional information, and 399 agreed to participate in the study, ultimately completing the MCT. One notable challenge highlighted by the science teachers was the demanding nature of the MCT. Furthermore, those who did not complete the MCT expressed difficulty generating and explaining/justifying four metaphors for the abstract concepts presented. Before data collection, all participants provided their informed consent by signing a form that outlined the study's general objectives and assured the confidentiality of the data corpus.

4.4 Data Management and Analysis

A total of 1596 metaphors were extracted from 399 science teachers, divided into four sections for qualitative analysis. Some data were excluded from further analysis due to various reasons. Firstly, teachers who did not consistently complete the MCT, producing metaphors for only one or two concepts, were removed. Secondly, irregularly written or submitted blank documents were also eliminated from the dataset. Thirdly, pseudo-metaphors created by participants were not included in the analysis. Saban (2010) emphasized the importance of assessing the structural qualities of metaphors in metaphor analysis to determine their authenticity. Three characteristics were considered to differentiate between authentic metaphors and pseudo-metaphors: (i) subject/content, (ii) connectivity, and (iii) fundamental reason (explanation/justification). The MCT specified the subjects/concepts, such as scientific knowledge, science concepts, science learning, and science teaching, for which participants were expected to produce metaphors. Their data were excluded if a participant used an alternative subject (e.g., scientific progression, philosophy of science) not included in the MCT. Connectivity refers to the interconnection between the metaphor produced by the participant ("the like") and the four concepts in the MCT ("the likened"). Furthermore, fundamental reasoning was assessed to determine whether participants provided logical warrants in explaining their underlying meaning position. An example of an authentic and pseudo metaphor from a participant science teacher is provided below.

4.5 Authentic Metaphor

The central concept in the MCT: "scientific knowledge."
Metaphorical externalization: "Snail shell."
The fundamental reason: "The snail shell symbolizes eternity. New information is constantly produced. Types of knowledge, such as theories, laws, and models, explain phenomena in nature. Sometimes, all existing knowledge may lose its validity with the production of new knowledge. However, the production process will always make scientific information the most valuable for that period."

4.6 Pseudo-metaphor

The central concept in the MCT: "scientific knowledge."
Metaphorical externalization: "scientific progression."
The fundamental reason: "Scientific knowledge is just like scientific development. As scientific knowledge increases, this leads to development and change in science. Just as we get older, our experiences, our knowledge of life, increase."

After rigorous data extraction and elimination, 304 science teachers' 1216 metaphorical reasoning around four concepts in the MCT was found relevant for further qualitative analysis. The unit of analysis in the present study was the generated metaphors and their explanations (fundamental reasons) (initial codes). Three steps of inductive data analysis were followed: open, axial, and selective coding. In the open coding, the participants' metaphors' explanations were labeled for breaking the data into smaller units. A line-by-line coding was followed during the open coding, where three researchers analyzed each data segment individually.

Example open coding:

The snail shell symbolizes ***eternity***. [*code*: scientific knowledge as something "**infinitive**"] New information is ***constantly produced***. [*code*: scientific knowledge as something "**cumulative**"] Types of knowledge such as theories, laws, and models explain phenomena in nature. Sometimes, all existing knowledge ***may lose its validity with the production of new knowledge***. [*code*: scientific knowledge as something "**tentative**"] However, the production process will always make scientific information ***the most valuable for that period***. [code: scientific knowledge as something "**tentative**"]

An initial coding catalog was established, characterized by its flexibility and dynamism. The catalog's content expanded as novel codes were added while assigning codes. The analysis of metaphors from 30 participants ($n = 120$) was conducted collectively by the three coders initially, followed by independent analysis for the remaining data. The kappa statistic was calculated using the formula [(n_{agreed} codes)/(n_{agreed} codes + $n_{\text{disagreed}}$ codes) × 100], as suggested by McHugh (2012), to measure the level of agreement. Intercoder reliability was assessed twice for all sections of open coding: scientific knowledge (kappa stats: first = 0.61; second = 0.83), scientific learning (kappa stats: first = 0.81; second = 0.93), science concepts (kappa stats: first = 0.69; second = 0.88), and science teaching (kappa stats: first = 0.89; second = 0.95). Notably, some kappa statistics fell below the accepted limit of 0.80. Consequently, the coders engaged in rigorous negotiations to internally persuade one another regarding the assigned codes' meanings, aiming to increase the credibility of the open coding and achieve higher kappa statistics.

Following the initial open coding process, axial coding was employed to establish associations between the analytical codes assigned to participants' metaphoric expressions. Two researchers examined the potential relationships among different codes to identify conceptual themes or categories. This involved gathering thousands of analytical codes to foster an integrated and systematic understanding of the data. Axial coding utilized a constant comparative approach whereby abstracted themes were continuously evaluated for internal homogeneity and external heterogeneity. The researchers consistently posed specific questions, such as "What is the core category connecting these codes?" In the final analysis stage, selective coding was performed to comprehend centralized and decentralized conceptual themes, enabling a coherent and integrated review of the data corpus. Specifically, transcendent conceptual themes were differentiated from particularized themes. This entailed reevaluating and verifying the conceptual themes obtained from axial coding to determine if a theme was present across all concepts, such as scientific knowledge (a transcendent conceptual theme), science learning, science concepts, or science teaching as outlined in the MCT, or if it was limited to one or two concepts (a particularized conceptual theme).

4.7 Trustworthiness

Two validation strategies were employed. Firstly, external audits with expertise in elementary and middle school science teachers' professional development were consulted at various stages of the study. These audits provided rigorous feedback on data analysis and interpretations. Their insights were precious in establishing internally coherent conceptual themes and higher-order categories derived from analytical codes through an inductive approach. Additionally, they assessed whether the researcher's interpretations and conclusions were well-supported and grounded in the data. Secondly, member checking was employed in specific metaphor sections related to scientific knowledge, science learning, science concepts, and science teaching. This step aimed to prevent over-interpretation of the data. Specifically, 49 participants actively participated in member-checking sessions for the metaphors associated with "scientific knowledge" and "science concepts." Their input was sought to verify and clarify the researcher-led analysis and interpretations. Through this process, the participants played a crucial role in refining and rectifying the researcher's understanding of the data, thereby contributing to the study's integrity.

5 Findings

This section presents the participants' metaphorical reasoning regarding four concepts about their profession with ample examples.

5.1 Scientific Knowledge

Under the scientific knowledge phenomenon, the teachers produced several metaphorical images to externalize their perceptions of scientific knowledge. First, the teachers conceived scientific knowledge as an "enlightening" device, tool, or source (e.g., sun metaphor, Table 1) that is functionalized for "emancipation" (e.g., freedom metaphor) or "guidance" (guide metaphor). Some others perceived scientific knowledge as an "endless" and "immortal" entity. This metaphorical idea shows that producing scientific knowledge or making sense of natural phenomena has no end if one looks closely at a phenomenon under investigation (e.g., the work of art you look at when you are bored metaphor, Table 1). In this sense, the teachers conceived data as the endless building blocks of scientific knowledge (e.g., black hole metaphor). Furthermore, these teachers apprehended scientific knowledge as immortal entities (e.g., the Mimar Sinan metaphor). This might imply that science teachers might perceive that scientific theories and laws of nature, which are inventions of scientists, are not tentative since they are immortal.

Based on some participant teachers' epistemological stances, science knowledge should be something "cumulative" and "infinitive" (e.g., avalanche metaphor, Table 1). Under this theme, the teachers stated that scientific knowledge (production) is an endless process of information/data gathering, ultimately leading to a new form of "ignorance" (e.g., a star's journey). Also, the participants characterized scientific knowledge or its production with the term "infinity": new knowledge can be replaced with old knowledge, but old knowledge has the best explanatory power of the time it is in (e.g.,

Table 1 The participant metaphors for scientific knowledge

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Scientific knowledge as an "enlightening tool"	Sun, compass, lamp, light, freedom, guide, lantern, light of the firefly, microscope, pole star, competent ophthalmologist, explorer…	*Sun* metaphor: Just as the sun turns nights into light, knowledge eliminates ignorance and enlightens humanity. We can only hold on to scientific knowledge in the dark *Freedom* metaphor: Ignorance is like a prison. Scientific knowledge frees man from the prison or captivity of ignorance. Knowledge liberates *Guide* metaphor: Every knowledge learned will come up somewhere to find the way. To make sense of events, our knowledge helps us find the right path and guides us. It includes everything about existence and non-existence. That is why scientific knowledge guides us in everything
Scientific knowledge as an "endless and immortal" entity	The work of art you look at when you are bored, infinity, the ocean, eating candy, space, black hole, sky, the sea with no end, personal file, endless wealth, Mimar Sinan…	*The work of art you look at when you are bored* metaphor: For example, sometimes you see work when you go to picture galleries. First, the work becomes meaningful. Then, it suddenly loses its meaning. But you assume there is a meaning. Then, the more you look, the more you will look. Because the meaning is there, but the goal is to know what it is *Black hole* metaphor: The more you want to learn, the more your desire to access information will draw you in. And the person finds himself in the data that will be lost like an endless black hole *Mimar Sinan* metaphor: Scientific information is like immortal works that will be discussed for many years. For example, the works of Mimar Sinan. They do not die

Table 1 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Scientific knowledge as something "cumulative and infinitive"	Piggy bank, avalanche, bank, snail shell, a star's journey, water, muscle…	*A star's journey* metaphor: The stars are many; you read their names in the book but cannot reach them all. You collect information, and then you collect it again, and then it all explodes into a black hole, and you realize that you know nothing because black holes are unknowable *Snail shell* metaphor: The snail shell symbolizes eternity. New information is constantly produced. Types of knowledge, such as theories, laws, and models, explain phenomena in nature. Sometimes, all existing knowledge may lose its validity with the production of new knowledge. However, the production process will always make scientific information the most valuable for that period *Water* metaphor: As the water flows, a new one comes. Just like knowledge, it never ends. It is always produced. A new one comes and accumulates
Scientific knowledge as something "sine qua non."	Vital nutrients, energy, food, protein, water, blood, medicine, oxygen, seeds, brain, ink…	*Protein* metaphor: Just as protein is the essential building block in forming living things, scientific knowledge is the building block of all kinds of science *Seeds* metaphor: When it meets the necessary conditions, it grows, develops, changes, and it pays off *Ink* metaphor: Ink is a basic need for writing. There is no civilization without the act of writing. If there is no civilization, you do not exist. That is why scientific knowledge is an indicator of civilization

Table 1 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Scientific knowledge as something "worthwhile"	Gold, money, silk cloth, diamond, house, treasure…	*Money* metaphor: The more scientific knowledge you get, the more you want it. Because knowing one thing attracts knowing something else. Money attracts money *Diamond* metaphor: As it grows, its value increases. Every scientific knowledge is a diamond particle. When it all comes together, it turns into a light source that we cannot look at with our naked eyes *Treasure* metaphor: It tells us about our life, what we are, and what we will be. In short, it allows us to find the meaning of life. Scientific knowledge is the treasure of this life
Scientific knowledge as something "providing power"	Castle, armor, winter coat, Hercules, power, treasure, ladder…	*Ladder* metaphor: The more you learn, the one step higher in life. It always takes us forward, up. Scientific knowledge is the only tool that can build ladders on ladders *Hercules* metaphor: When you equip yourself with scientific knowledge, you become like Hercules. Strong, helping people, protecting against evil *Treasure* metaphor: Scientific knowledge is the basis of technology. Technology is also the basis of development. If you have the technology, you have the power. Technology is a treasure in every sense
Scientific knowledge as "discovery"	Nature, world, pearl, patience, labyrinth, secret, thought, product between being and object, a pair of shoes…	*Pearl* metaphor: Removing the pearl from its hiding place is necessary. This is a complete discovery process. Efforts are made for this. This is the case with scientific knowledge; reaching knowledge is labor *Product between being and object* metaphor: The subject (being) makes judgments about and explains the object by interpreting it. For example, we might judge that an object that attracts metal objects is a magnet

Table 1 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Science knowledge incorporating different "features"	The highway connecting a crossroad, chameleon, pearl, octopus, everything, car with full tank, skyscraper…	*The highway connecting an intersection* metaphor: Although there are many different ways to go, there is only one correct information to reach *Chameleon* metaphor: There is no absolute truth. However, the color may appear different to us. Therefore, scientific knowledge is secure knowledge

snail shell or water metaphors). In these metaphorical conceptions of scientific knowledge, implications show that scientific knowledge is tentative and progressing. However, the teachers implied that scientific knowledge progression is cumulative, like T. S. Kuhn's normal science conceptualization.

It was embedded in some teachers' metaphors that scientific knowledge is something "vital" or "sine quo non." This metaphorical theme is more about functional and attitudinal tendencies toward scientific knowledge. The science teachers generated metaphors under this theme, showing that scientific knowledge is a functional need (e.g., protein metaphor, Table 1) or analytical unit (e.g., ink metaphor) of all wisdom of humanity. Similarly, some participatory science teachers perceived scientific knowledge as a significant or "worthwhile" entity. These teachers conceived the science knowledge phenomenon as an object with a cost or value in return. According to the participants, more scientific knowledge leads us to even more scientific knowledge (e.g., money metaphor). Since each piece of scientific information is valuable, their sum is invaluable (e.g., diamond metaphor). Also, since scientific information can give us the meaning of our lives, it becomes a precious object (treasure metaphor). All these metaphorical images of the science teachers imply that they were motivated and enthusiastic to have scientific knowledge as money.

Similarly, some science teachers conceptualized scientific knowledge as a "power source." The participants showed with their metaphorical reasoning that there is a relationship between having scientific knowledge and "leveling up in life" or "going to the next level in life" (e.g., ladder metaphor). Some participants also expressed scientific knowledge as a protective belt and presented it as a force against evil from a mythological perspective (e.g., the Hercule metaphor). In addition, the participants reflected through their metaphors how basic scientific knowledge drives technology and that technological capacity is a power.

Some of the generated metaphors of the teachers were dedicated to the production process of scientific knowledge, such as "discovery." Some participants stated that producing scientific knowledge or discovery can be realized through a particular effort (e.g., the pearl metaphor). Another metaphorical reasoning of the participants implies that the logic of scientific discovery needs the human mind (being); the mind perceives and interprets it and arrives at some nature-related pattern (e.g., the product between being and object metaphor). In the last theme of the scientific knowledge metaphors, the participants listed some qualities of what-aspect or "generic features" of scientific knowledge. The metaphorical images of the participants regarding generic features of science knowledge were mixed. For instance, on the one hand, they were of the idea that there may be different or alternative solutions to a problem. However, the truth as a composition is ultimately single (e.g., highway connecting an intersection metaphor). On the other hand, some participants indicated that current scientific knowledge is not the ultimate truth about a natural phenomenon. They added that their reflections can be observed differently than a natural phenomenon. More importantly, they expressed that understanding scientific knowledge as "phenomena" ("…However, the color may appear different to us.", Table 1) makes it credible (e.g., chameleon metaphor).

In summary, in externalizing their perceptions, the science teachers used metaphors to depict scientific knowledge as "enlightening," "endless," "cumulative," "vital," and a "power source." Metaphors highlighted its role in discovery, emphasizing effort and the interaction between the mind and the object. Teachers also considered generic features, suggesting diverse solutions and scientific knowledges dynamic, credible nature.

Table 2 The participant metaphors for learning science

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Learning science as acquiring something "cumulative"	Snowball, matryoshka, key, digging in the mine, swimming, building, chain, playing hide and seek, fire…	*Fire* metaphor: "When you throw the fire somewhere, it will dissipate as soon as it stops. It goes wherever it can, and it ignites everywhere. It is like learning science concepts. That is, you want to learn as you learn." *Digging in the mine* metaphor: "As you learn science concepts, you gain deeper knowledge about the subject. As we learn new concepts, the subject gets deeper, and we want to go deeper with the curiosity of what will come our way as the learning continues this way."
Learning science as learning an "endless cumulative"	Space, universe, diving, galaxy, ocean, river…	*Space* metaphor: There is endless information to be learned, researched, and known. It is infinite. Learning is endless in our life. Learning science is also an endless process *River* metaphor: It is like streams that open into a vast sea of knowledge. It contains an endless amount of information. There is always something new coming out. It makes you wonder. You do not know the end, but you cannot stop yourself from going to the end of the stream
Learning science as applying "inductive reasoning"	Metrobus lining, map, sleeping on a soft bed, seeing behind the scenes, back to the future, dominating and controlling nature…	*Metrobus lining* metaphor: When traveling by metrobus (the public vehicle with an allotted road used in Istanbul), you should immediately press the stop button and get off the metrobus at the next stop when the smells start to come from the linings *Back to the future* metaphor: It is diverse and makes people conscious and resilient to every situation. You do not need to see the future with magic balls, and you can see the future if you learn science

Table 2 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Learning science for to be "illuminated"	Light bulb, enlightening vehicle, understand the universe, coffee, light, flashlight, central light source, fire, torch, laser, sun, star…	*Coffee* metaphor: It is delightful and opens one's mind like caffeinated coffee. You will immediately fall asleep as if a light has been shined on your eyes. It increases awareness and brings you closer to reality. You walk sober *Central light* metaphor: Learning science helps people understand their physical relationship with the world and the universe. When I learn science, I become aware of my formation. I understand what kind of existence I am a part of. For this, we need a leading power, an illuminating source
Learning science for "living better"	Living, driving, learning to use the flashlight, compass, life menu, comfort, weather, life book…	*Life book* metaphor: Although sometimes serious difficulties arise in our complicated life, every concept learned in science has a place in life. So, it has a facilitating function. Of course, every concept learned is needed one day *Life menu* metaphor: Learning science means reading life's menu correctly. If you eat a meal that is not good for you that day, your health will deteriorate. Your stomach hurts. Therefore, learning science is like choosing the right one from the life menu

Table 2 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Learning science for "meaning making" of natural phenomena	Interpreting daily life, the world, nature, exploring nature, traveling to the world, discovery, three-dimensional film, experiencing reality, discovering everything, a long journey of discovery, opening the doors of the unknown…	*Three-dimensional film* metaphor: It is starting to look at the mundaneness of the day with a different eye. Science learners recognize and describe the world. Everything is straight when you look at the screen. The events are embedded on the screen. But if you watch the movie in 3D, you will feel like you are in all the events. This means that you can "touch" reality *A long journey of discovery* metaphor: Traveling is good. All journeys, short or long, are beautiful. Good or bad, something can happen to a person during a journey. For example, you may lose your bag. Searching and finding the bag requires exploration. We remember our travels clearly. Every journey is an encounter. It is full of surprises
Learning science as reacting to a "cognitive load"	Sun, walking in the forest with one eye, shopping mall, climbing Mount Everest, puzzle, growing up, swimming, eating chocolate cake, Picasso paintings…	*Picasso paintings* metaphor: Although it may seem meaningless at first glance, it contains deep meaning. But understanding this requires profound imagination. This is very mind-blowing. The universe always seems disorderly, but as you descend into the world of atoms or tiny, the universe becomes beautiful on both a small and a large scale *Shopping mall* metaphor: It might sound a little confusing. It consists of complementary wholes. But it is not easy to understand. It's like a labyrinth. You never know which room to go from which room. Or get lost in the corridors. This makes you very, very tired

5.2 Learning Science

The science teachers produced diversifying "science learning" metaphors (Table 2). First, they imagined that science learning is to acquire something "cumulative" (e.g., snowball, matryoshka). For some teachers, science learning implies the accumulation of their knowledge progression over time (e.g., digging in the mine). They also believed that learning science is like accumulating knowledge pieces that open new paves for knowing natural phenomena (e.g., playing hide and seek). They understood science learning as a process of approximating a version of reality (e.g., playing hide and seek). These metaphorical imaginations imply that they held conventional epistemic beliefs about science (learning), showing that science is a pool of accumulating factual knowledge pieces. Similarly, they comprehended learning science as acquiring an "endless cumulative" (see examples in Table 2). As seen in the explanation of the "space metaphor" (Table 2), a participant conceived learning science as an infinite task. Moreover, the "river metaphor" presents that science learning is cumulative but endless. This metaphor also represents the infinite or endless curiosity and open-mindedness regarding science learning.

The "inductive reasoning" category means that the participants perceived science learning as a precautionary human activity (Table 2). The participants explicitly attributed the linkage between inductive-protective thinking and causal reasoning within this category. For instance, by the "Metrobus lining" metaphor, a participant narrated how science learning and protective actions are interrelated. This metaphor implies that science learning informs us about future occurrences that may have adverse effects. Similarly, as expressed through the "back to the future" metaphor, a participant metaphorically summarized how learning science informs us about the future. She mentioned that people must learn science instead of looking at a magic ball. With the inductive reasoning metaphor, it can be asserted that the participants reflected a verificationism orientation as an epistemic stance regarding how science works and generates the knowledge that the participants learn.

Based on the inductive reasoning category, the participants also generated metaphors implying that science learning is "illuminating" and is instrumentalized for better "living conditions" (Table 2). In the learning science for to be illuminated category, science learning is used as a tool for being illuminated or having conscious awareness and being evoked about happenings. For instance, with the "coffee" metaphor (Table 2), the participant explicitly expressed that science learning is an awakening, evoking, or alerted activity. Staying in a condition of being alerted, as the participant metaphorically documented, brings a conscious awareness regarding the happenings of the natural world in which we live. In addition, with the "central light" metaphor (Table 2), a participant indicated that science learning could be a way of developing an introspection. This implies that learning science attaches internal (person) and external (physical-material world/universe) in the sense of "knowing yourself" (see details of the central light metaphor in Table 2).

Learning science for living better category is characterized by different metaphorical verbalizations of the participants, such as necessary experiences in the form of conceptions, an interrogation of reality for living better, a way of adaptation, learning how to live, a thinking tool to live better, and having a wise guide to live. A participant stated that each learned science knowledge has (will have) its function in a phase of human life for living better (e.g., life book). For living better, as a participant narrated, science learning provides us with precautionary information about actions such as eating (see the "life menu" metaphor). As embedded in this metaphor, the participant perceived science learning as developing a thinking toolkit in which different elements (learned knowledge pieces) are selected and operated in an appropriate time and context.

Some participants also conceived science learning as "meaning making" of natural phenomena (Table 2). They mentioned that science learning provides a different lens of understanding everyday occurrences (e.g., interpreting daily life, Table 2). When they learn science, as they narrated, they are engaged in knowing and making sense of the world (e.g., the world). From the lens of the teachers, science learning is to have a comprehensive understanding regarding something conscious, such as nature (e.g., machine nature). As the teachers indicated, science learning resembles establishing a cognitive mapping of the materialized universe (e.g., traveling to the world) by understanding and meaning-making of natural and social phenomena (e.g., discovery, as detailed in Table 2). The teachers expressed that science learning is a way of understanding the subject of the universe and its actions (e.g., three-dimensional film, as detailed in Table 2). They also attributed the linkage between learning science by doing science for sense-making (e.g., experiment). They considered science learning as constructing a thinking tool connecting micro-cosmos and macro-cosmos (e.g., opening the doors of the unknown).

Finally, some participants perceived science learning as reacting to a "cognitive load" (see the expressions for the "Picasso paintings" metaphor in Table 2). They expressed that during science learning, they felt a version of cognitive load or overload (e.g., walking in the forest with one eye, Table 2). As embedded in the participants' metaphors, science learning is needed to grasp a pool of complicated and conflicting knowledge and information (e.g., see the "shopping mall" metaphor as detailed in Table 2). As learning science is a way of intellectual maturation (e.g., growing up), it requires cognitive overload, as the participants conceived. Moreover, they mentioned that learning science is challenging since it is a brain-based activity pressing one's brain cells for intellectual activity and productivity (e.g., swimming sport).

In summary, the participants used metaphors to portray diverse perspectives on "science learning." Some saw it as a "cumulative" accumulation of knowledge, while others viewed it as "endless cumulative," an infinite task. Metaphors linked it to inductive reasoning, emphasizing its role in protective actions and causal reasoning. The teachers also depicted it as "illuminating" and instrumentalized for better "living conditions." Additionally, some perceived science learning as "meaning making" and others as reacting to a "cognitive load," challenging but crucial for intellectual maturation.

5.3 Science Concepts

First, the participatory teachers conceived science concepts as a "holistic" structure (Table 3). This implies that they believed science concepts are not individual or isolated pieces but integrated parts of a consistent whole. For instance, with the DNA and tiny puzzle papers metaphors (Table 3), the participants summarized the resemblance between how the genetic material regulates all aspects of an internally consistent organism ("…constitute a meaningful hereditary material") and "meaningful" integration of science concepts to understand natural phenomena. In the second metaphorical theme, the "vitality" of science concepts was emphasized by the participants. Around this theme, for instance, with the token metaphor, a participant described how science concepts are used as tools and purposes for developing our life knowledge. In addition,

Table 3 The participant metaphors for science concepts

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Science concepts as something "holistic"	DNA, chain, tiny puzzle papers, jigsaw puzzles, lyrics, links of the chain, chain, theatre, spider web, maze, wagon, train track, building material, computer network…	*DNA* metaphor: Just as genes with a particular trait constitute a meaningful hereditary material, science concepts also show the vital whole that enables the emergence of traits for all inanimate and living things *Tiny puzzle papers* metaphor: When it all comes together, the puzzle is completed, and a meaningful photograph emerges. The person discovers natural phenomena through the photograph. Each concept is related to the others and enables us to understand the phenomena of nature
Science concepts as something "vital."	Cold water sipped in an August heat, cell nucleus, death, seed, life, air, water, token, food, world, rain, medicine, breathing while sleeping, bag, nature, computer…	*Token* metaphor: We need tokens to get on the subway. To progress in life, we need to know the concepts of science. But science concepts are not just tools. They are things we must learn. So, it is our aim *Rain* metaphor: Just as rain brings life to the soil, science concepts also give life to other sciences. The development of other sciences depends on producing scientific concepts and reaching a consensus on them
Science concepts as something "enlightening"	Key, sun, lens, guide, lantern, Google, index of a book, parts that make up the lantern, encyclopedia…	*Index of a book* metaphor: It helps you by showing you which page you are looking for. For him, science concepts are not random. All of them unite or diverge under specific themes *Key* metaphor: If the universe is a massive door with millions of locks, science concepts are the keys to these locks
Science concepts as something "fundamentals"	Nuclear power plant, building foundation, stairs, face recognition system, prospectus, prescription…	*Nuclear power plant* metaphor: Just as hydrogen provides energy to the sun by radioactive reactions and makes the sun active, science concepts also provide energy for science and keep science dynamic *Prospectus* metaphor: Just seeing what happens in nature is not enough. It is necessary to understand what is happening there systematically. This requires manuals with specific guidelines in them. These are science concepts

Table 3 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Science concepts as something “massive”	Hot pepper, metrobus, knot, boomerang, counting numbers, soup, space, swirl, step, love, ocean, a precious metal, sky, infinity, sky, ocean, well…	*Boomerang* metaphor: When you throw it away, it returns and finds you. You cannot get rid of them with simple thinking methods *Soup* metaphor: It starts with one and continues with two. It goes from simple to complex forever. At first, everything is clear, and then it becomes clear that nothing is clear *Metrobus* metaphor: Each one is full of many sub-meanings; it comes one after another. You cannot skip one and move on to the other. Even if you do not like it, you must learn the other before moving on to one
Science concepts maintain “symbolic interaction”	Symbols, telescope, fertile land, play dough, instruction, speech of objects, symbols, language teaching…	*Symbols* metaphor: Every element, every substance, and every law has a name in the literature. It also has a symbol or a letter to represent them. Every concept has a symbolic meaning *Speech of objects* metaphor: Science concepts reduce complexity in the expression of issues related to the environment in which we live and provide a systematic grouping of information *Language teaching* metaphor: Science concepts are like a shortcut to understanding life. They are symbols of cause-effect relationships. It is another language. It is written with other letters, syllables, words, and sentences

with the rain metaphor, the participant explained the vitality of science concepts for all science disciplines and added that the progression of science requires both the production of science concepts and an agreement on them.

Some science teachers believed science concepts are "enlightening" tools, such as the book index carefully designed and classified for specific purposes and certain readers. Moreover, with the key metaphor, a participant implied that science concepts are devices for unfolding the mysteries of the material universe. For some participant teachers, science concepts are "fundamentals" or the fabric of diversifying science disciplines. For instance, a participant with the nuclear power plant metaphor indicated science concepts as analogous to hydrogen fueling the sun's radioactive reactions. In this metaphor, science is likened to a dynamic system similar to the sun, sustained and energized by the constant interaction and application of scientific concepts. The metaphor emphasizes that just as hydrogen keeps the sun active, science concepts serve as the driving force that keeps the field of science vibrant and in motion. A participant conceived science concepts as the meaningful pieces of a user guide (e.g., prospectus metaphor) by which one tries to systematically comprehend the mechanics of the universe in which s/he lives. Some participants perceived science concepts as "massive." The massiveness of science concepts, based on the metaphorical documentation of the teachers, is more related to the cognitive load. For instance, with the boomerang metaphor, a participant declared that science concepts are sticky, and one has to try to acquire or "get rid of them" instead of engaging in simplified reasoning. With the soup and Metrobus metaphors, the participants stressed that science concepts are not simplified entities; they are sophisticated mixes and, therefore, incorporate several sub-episodes that cannot be overlooked if one desires to have an integrated apprehension of them.

Finally, under this concept, the science teachers believed that science concepts are "symbolic" tools operated for communicative purposes. From a participant's viewpoint, science concepts are mere markings of natural happenings embedded in the related literature, reflected in the "symbols" metaphor. On the other hand, some other science teachers stated that science concepts are beyond mere labels. For instance, with the speech of objects metaphor, a participant depicted that science concepts are tools as meaning carriers by lessening the sophistication of natural phenomena or making the natural occurrences more understandable. In the speech of objects metaphor, the participant also stated that science concepts are abstraction (generalization) systems for regularly organizing cumulative information. Lastly, with the language teaching metaphor, a participant perceived science concepts as specific thinking and talking or explanation systems for certain or private purposes of different groups whose members use customized letters, syllables, words, and sentences.

In summary, the participants saw the science concepts as a "holistic" structure, integrated and consistent, like DNA regulating an organism. Emphasizing the "vitality" of science concepts, teachers viewed them as tools for life knowledge and essential for scientific progress. Some believed science concepts are "enlightening" tools, while others considered them "fundamentals" or the fabric of science disciplines. Participants also saw science concepts as "massive," requiring effort to acquire or comprehend. Finally, teachers perceived science concepts as "symbolic" tools for communication, conveying meanings, and organizing information.

Table 4 The participant metaphors for teaching science

Themes	Sample metaphors	Explanation/justification of the stated metaphor
"Transferring" different forms of science knowledge	Interlocking rings, matryoshka, opening an herbal shop, fairy tales of the Arabian nights, puzzles, rivers, painting, going uphill, planting seeds, growing flowers, farming, gardening, motherhood, raising a baby, money deposited in a savings account, filling an empty bucket with water, a computer…	*Painting* metaphor: It is like making a brush stroke on the canvas (student) with the colors that come from the artist's knowledge, that is, his/her accumulated knowledge *Motherhood* metaphor: Like a mother who teaches concepts in every part of her life… She raises her children to prepare them for life. She wants them to show what she teaches at some point in life *Money deposited in a savings account* metaphor: Its value increases over time. Every learning needs time to be given. But time alone is not enough. A serious investment is also required. If the investment is good, the profit is also good
Teaching science for "illuminating"	Giving advice, guide, light, lantern, sun, sunrise, illuminating a dark path, lighthouse, giving someone a compass, guiding a tourist, opening the curtain, lamp…	*Giving advice* metaphor: It changes students' perspective on life. When they cannot find their way in the name of science, the best thing is to dialogue with them and give advice *Opening the curtain* metaphor: The teacher opens the curtain and shows what needs to be seen. The tie that will open the curtain is in the hands of the teacher *Illuminating a dark path* metaphor: As students learn science concepts from me, they see and recognize themselves, their environment, the world, and the universe
"Motivational motives" for teaching science	Chocolate, water, nutrition, making music, skating, candy, showing love, making inventions, jumping on the trampoline, participating in the festival, living the best memories, love…	*Chocolate* metaphor: It is addictive. The more you teach, the more you want to teach. Eventually, you start teaching outside the classroom and become an addict *Participating in the festival* metaphor: You show different feasts in every part of the festival. Each festival tent represents another love of teaching entertainment *Jumping on the trampoline* metaphor: It is fun and dynamic. The higher you jump, the higher you want to go. But the levels of the students allow it

Table 4 (continued)

Themes	Sample metaphors	Explanation/justification of the stated metaphor
Science teaching brings about higher "pedagogical cognitive load."	Horror movie, a long journey, climbing the mountain, being patient, ditching the camel, untying the knot, climbing the mountain, hot pepper, being a porter, trying…	*Horror movie* metaphor: Even though it is scary to watch, you find yourself watching. Teaching science is complicated, just like watching a horror movie. But eventually, you will because it gives a taste you can't taste anywhere else *Ditching the camel* metaphor: The capacities and perceptions of the students may not be very suitable for this *Being a Porter* metaphor: In every incomprehensible concept, it may be necessary to go back to the beginning again and explain the subject or concept. It is a labor-intensive process
Science teaching for "preparing students for daily life"	Water, life, raw materials, medicine, to make life understood, to explore the area where it lives, to live, to teach life, to donate organs, public service ads, nature…	*Nature* metaphor: When we look at nature, there is so much that we need to learn from it… To understand life, we need to learn a lesson from every particle. For this reason, we will be successful if we can associate science concepts with life while teaching them *Public service* metaphor: The concepts are very real (scientific) and complex. To teach these, it is necessary to associate them with social life and make them comprehensible by proving their usefulness by referencing daily life. In other words, it is necessary to attract the student's attention to what it does and make it understandable
Science teaching as acting as a "guide"	Pole star, tourist guide, being a captain on a ship, compass, key, guide, raising explorers, map, user manual…	*Being a captain on a ship* metaphor: You can only help someone find their way, and in doing so, you are doing your duty to yourself and everyone, not just that person *Map* metaphor: To offer new solutions to scientific problems that people have created in their minds. In other words, it is collaboratively constructing maps with alternative routes and paths

5.4 Teaching Science

The participants also generated diversifying metaphors regarding science teaching, exemplified in Table 4. The most dominant metaphorical theme was science teaching as "transferring" different forms of scientific knowledge. This implies that knowledge transmission modes of science teaching are still on most participant teachers' agendas. For instance, with the painting metaphor, a teacher perceived science teaching as shaping one's cognition or acquisition. Similarly, with the motherhood or money deposited in a savings account metaphors (Table 4), some teachers conceived science teaching within the framework of the banking model of (science) education where first an investment is made in a student, that investment is valued over a certain period, and the invested person should be able to show that the investment made in her increases when the time passed. The second most pervasive metaphorical theme extracted from the teachers' science teaching metaphors is "illuminating," which is used in teacher-centered science teaching orientation. To justify, based on the proposed metaphorical images, the teachers considered science teaching as an advising mechanism (e.g., giving advice metaphor) by which they open different paves for students in a thick forest (e.g., illuminating a dark path metaphor). As a note, the "illuminating" theme that emerged under the teaching science concept is conceptually or metaphorically different from other themes such as "enlightening tool" (scientific knowledge), "illuminated" (science learning), or "enlightening" (science concepts) observed within different concepts. The first three "illumination-related" themes are about the teachers' illumination through scientific knowledge or learning science or science concepts. However, in the science teaching metaphors' scope, the "illumination-related" theme implies the transmission of the light of the teacher as the light stands for knowledge. For instance, a participant with the opening the curtain metaphor expressed that the teacher owns the knowledge that guides students ("…The tie that will open the curtain is *in the hands of the teacher*.", Table 4).

As captured from the metaphorical externalizations of the teachers, they were eager to teach science, expressed within the "motivational motives" for teaching science theme. The teachers produced metaphors incorporating their enthusiasm during science instruction. For a participant with a chocolate metaphor, science teaching is continued out of the classroom since teaching science causes addiction. Another participant participating in the festival metaphor indicated that each science topic presents different entertainment. A participant also metaphorically stated that she "constantly raises the gears" when teaching a science subject or engaging with students on more profound topics. However, this should be allowed by students' cognitive readiness.

Even though a significant part of the participatory teachers were enthusiastic about teaching science, a considerable part of them found it difficult, sophisticated, or troublesome under the theme of "pedagogical cognitive load" (Table 4). For example, a participant metaphorically expressed the challenging side of science teaching with a horror movie metaphor. With the ditching of the camel metaphor, a science teacher explained how teaching science could be more complicated when students' readiness is considered. The requirement of the rehearsals that occurred in science lessons to ensure students captured every concept was also metaphorically expressed by using a Porter metaphor.

Under the theme of "preparing students for daily life," some teachers metaphorically stated that science teaching should be operated to teach students about natural phenomena. Therefore, science teaching should be based on everyday natural incidents (e.g., nature metaphor, Table 4). Similarly, if science teaching is carried out by making concrete linkages to students' everyday lives, it would be easier or instrumental for them to acquire the intended science concepts. In the last theme produced for the science teaching concept, the "guide" theme (Table 4), some teachers conceived teaching science more contemporary or within a constructivist perspective. For instance, as a captain on a ship metaphor, a participant described how she should act as a supporter who operates scaffolding tasks more broadly by going beyond the classroom. With the map metaphor, a participant also emphasized cooperative actions in generating alternative solutions for emerging problems.

In summary, the dominant theme was teaching as "transferring" knowledge, resembling shaping cognition or banking on investment. Another prevalent theme was "illuminating," portraying teaching as advising, opening paths, and transmitting the teacher's knowledge. The participants also used metaphors to convey "motivational motives," highlighting enthusiasm, addiction, and the entertaining aspects of teaching. Some found science teaching challenging, expressing "pedagogical cognitive load" through metaphors like horror movies and complicated journeys. The teachers emphasized "preparing students for daily life," advocating linking science teaching to everyday experiences. Lastly, the "guide" theme depicted teaching as supportive and constructivist, like a captain guiding a ship or providing a map.

6 Summary and Discussion

Table 5 displays metaphorical conceptions organized into five higher-order conceptual themes. The cross-tabulation presented in Table 5 allows for vertical and horizontal evaluations of the diverse participant expressions regarding their epistemic cognitions. Table 5 displays the communalities and differences across the themes deduced from the analytical metaphorical externalizations of the participants to present an integrated picture of their epistemic cognitions. In other words, meta-themes were extracted by re-examining the epistemically oriented conceptual themes around the four concepts to identify the integrated essences embedded in the data. Based on this purpose, five higher-order or meta-themes were constructed, and this section is structured based on them: function, personal epistemological stance, motivational construct, sociological construct, and pedagogical construct.

6.1 Function

First and foremost, Table 5 illustrates that the concept of function was prevalent across all metaphorical conceptual themes derived from participant expressions. In the context of this study, the notion of function suggests that an instrumentalist perspective predominantly influenced participants' epistemic cognitions. Through their metaphors, participants conveyed four concepts related to science and the learning/teaching of science, emphasizing their instrumental value in illuminating social and natural phenomena, meeting basic human needs, and improving living conditions. In other words, participants viewed science and the learning/teaching of science as tools with diverse functions, as reflected in their metaphors. This suggests that participants embraced an instrumentalist perspective or Deweyan pragmatism (Quay, 2013), focusing on the practical usefulness and instrumental value

Table 5 Crosstabulation across the higher-order themes and extracted metaphorical themes

Higher-order themes	*Extracted metaphorical themes*			
	Scientific knowledge	Science learning	Science concepts	Science teaching
Function	• Enlightening tool • Sine qua non	• Illuminated • Living better	• Vital • Enlightening • Fundamentals	• Illuminating
Personal epistemological stance	• Endless and immortal • Cumulative and infinitive • Discovery • Features	• Cumulative • Endless cumulative • Inductive reasoning	-	-
Motivational construct	• Worthwhile	-	-	• Motivational motives
Sociological construct	• Providing power	-	-	-
Pedagogical construct	-	• Meaning making • Cognitive load	Holistic, massive, symbolic interaction	• Transferring • Pedagogical cognitive load • Preparing students for daily life • Guide

of scientific ideas, theories, and concepts rather than their credibility or correspondence to reality (Toscano & Quay, 2021). The instrumentalist view posits that scientific theories and concepts serve as mere tools (e.g., compass, lamp, light, Table 1) for making accurate predictions and solving practical problems (e.g., "life menu" metaphor, Table 2) (Toscano & Quay, 2021). Dewey (1916; 1934) argued that scientific theories should be regarded as tools for problem-solving and advancing practical knowledge, which aligns with the opinions expressed in the majority of participants' epistemic cognitions manifested through their metaphors (e.g., the "life book" metaphor in Table 2). The instrumentalist perspective emphasizes evaluating scientific theories based on their ability to explain and predict phenomena and their utility in guiding human action and technological advancements (Toscano & Quay, 2021). Through their metaphors, participants seemed to attribute significance to scientific knowledge and its teaching/learning in the context of humanity's progress (e.g., "token" metaphor in Table 3), reflecting an instrumentalist epistemic cognition.

The instrumentalist epistemic cognition evident in the participants' metaphors can be attributed to the explicit influence of specific and general aims outlined in the science curricula for grades 3 to 8, recently implemented in Turkish elementary and middle schools. These science curricula emphasize the relevance of "daily life" phenomena and aim to educate students to tackle real-life problems across various domains (Aydin et al., 2022). Educational policymakers have defined the primary objective of the implemented curricula as follows: "To take responsibility for daily life problems and to use science knowledge, scientific process skills, and other life skills to solve these problems" (The Ministry of National Education, 2018; p. 9). Similar aims are reiterated in different sections of the curricular documents. It is well recognized that science teachers play a crucial role in translating curricular aims and objectives and constructing their pedagogical content knowledge when teaching science concepts and skills to students. Thus, the instrumentalist epistemic cognition described above can be seen as an anticipated outcome of implementing science curricula that aim to equip students with a knowledge base and thinking skills to address real-life, contextualized, and situated problems.

To support this notion, it is worth noting that in addition to well-known developmental and dimensional models that explain science teachers' epistemic cognitions, Chinn and Rinehart (2016) argue that epistemic cognition is socially constructed. Furthermore, Chinn and colleagues (e.g., Chinn et al., 2011, 2014) emphasize that epistemic cognition is situated within a specific context. This suggests that naturalized epistemology challenges the established foundations of developmental and dimensional models in traditional epistemology. The present study demonstrates that having an epistemic cognition that describes science and its teaching/learning in an instrumentalist manner may arise from the participants' active engagement with science curricula that aim, in every aspect, to educate students as problem solvers in real-life situations. This point can be supported by the related literature on context-based or case-based science instrumentality and its instrumentality in intellectual development. For instance, with the nature metaphor (Table 4), the teacher emphasized that knowledge can be gained from observing and understanding the natural world. The teacher suggested that students can benefit from approaching science as a study of life, learning valuable lessons from every aspect of nature (e.g., "For this reason, we will be successful if we can associate science concepts with life while teaching them.", Table 4). Similarly, Dori et al. (2018) stressed that this instrumentalist perspective, by embedding science concepts in real-world problems (Herscovitz et al., 2012), encourages a holistic understanding of scientific concepts, implying that students should not just memorize facts but should also appreciate the interconnectedness of scientific principles with the world around them. In other words, the instrumentalist perspective, which was embedded in the participatory teachers' metaphors or epistemic cognitions, implies a context-based or case-based science teaching style by which teachers should adopt an approach that fosters curiosity, exploration and an appreciation for the relevance of science in daily life (Dori et al., 2018).

6.2 Personal Epistemological Stance

As seen in Table 5, specifically, the metaphors generated under the categories of scientific knowledge (Table 1) and science learning (Table 2) provided insights into their personal epistemological orientations. The participants' epistemological stances predominantly revolved around two discourses: viewing "scientific knowledge" or "science learning" as endless, immortal, cumulative, and infinite. These metaphorical representations indicated that the participants may have developed epistemic cognition, suggesting that science is an accumulation of primarily static (immortal) facts. The static nature or certainty associated with scientific knowledge (Bahcivan, 2019; Bahcivan et al., 2019) can be understood in light of previous developmental models (Perry, 1968) or dimensional models (Schommer, 1990) of epistemic cognition.

In addition to the participants' epistemic cognition that emphasized the unchanging nature of scientific knowledge, they also appeared to believe that scientific knowledge, and consequently, science learning, is endless and cumulative. This inclination aligns with T. S. Kuhn's concept of normal science as a version of epistemic cognition (Kuhn, 1970). Given the significant impact of Kuhn's ideas on science education (e.g., Matthews, 2022), normal science can provide insight into the participants' emphasis on the cumulative nature of scientific knowledge and its learning. According to Kuhn (1970), the objective of normal science is to accumulate knowledge and make incremental progress within the boundaries set by the prevailing paradigm. It represents a period during which researchers operate within established frameworks, theories, and methods, all within the accepted scientific paradigm (Kuhn, 1970). During this phase, scientists solve puzzles and address anomalies within the existing paradigm, contributing to a deeper understanding of the subject matter. In essence, normal science entails conducting experiments, collecting data, and refining existing theories to enhance the understanding of the subject matter. However, when anomalies and challenges accumulate significantly, they can trigger a crisis that may ultimately lead to a paradigm shift and a new era of scientific revolution (Kuhn, 1970). From Kuhn's perspective, the progression of scientific knowledge encompasses both an evolutionary (accumulative) and revolutionary (paradigm shift) structure (Matthews, 2022). The present study demonstrated that the science teachers' epistemic cognition primarily incorporated the evolutionary aspects of scientific knowledge and its learning, as reflected in their metaphorical expressions. In other words, the revolutionary aspect of scientific knowledge and its learning was not evident in the participants' metaphors.

One of the main factors contributing to this surface-level epistemic cognition can be attributed to the nature of science teacher training and the textbooks used in these training programs. Teaching subject matter knowledge in science to prospective teachers often follows a cumulative approach, where discoveries are built upon existing knowledge, accumulating scientific knowledge. This reinforces a confirmatory and simplified understanding of how science operates and progresses. Furthermore, Kuhn (1970) emphasized that textbooks and other educational materials can be designed to support the conventional viewpoint, portraying the accumulation of scientific facts as an explanation for the progression of scientific knowledge. However, Matthews (2022) strongly critiques this perspective, highlighting that this surface-level epistemic cognition concerning the nature of scientific knowledge, how science functions, and how individuals acquire scientific knowledge is essentially a result of teacher training traditions.

6.3 Sociological Construct

Matthews (2022) argues that developing a deeper understanding of scientific knowledge and the workings of science is not a random or automatic process. As a solution, Matthews (2022) strongly recommends that teaching history, philosophy, and sociology of science should be integral to teacher training and professional development programs. However, Matthews (2022) interprets the absence of these components in teacher education programs as a fundamental flaw: "This indicates a fundamental deficiency in the discipline: The failure to incorporate history and philosophy of science into teacher education or graduate programs" (p. 6). The present study suggests that a similar situation exists in the Turkish context, as internationally, science teacher education and research often lack input from the history, philosophy, and sociology of science (Matthews, 2020, 2022). The global situation described by Matthews (2020, 2022) is also reflected in the qualitative data obtained from participating science teachers, as only a few metaphors ($n = 6.25\%$; Table 5) were generated concerning scientific knowledge's sociological aspects. Although metaphors related to the sociological boundaries of scientific knowledge were present under the conceptual theme of providing power (Table 1, e.g., "treasure" metaphor), their representation among other conceptual themes was considerably limited.

6.4 Pedagogical and Motivational Construct

Previous studies have demonstrated that science teachers' epistemic cognition significantly influences their science teaching approaches, strategies, and pedagogical decision-making during classroom interactions (Suh et al., 2022). The current study highlights a connection between the teachers' metaphors, conceptual themes, and higher-order categories (Table 5). First, under the higher-order theme of motivational construct, the teachers explicitly indicated that they found scientific knowledge worthwhile, so it should be taught in the schools, showing direct and tangible interrelations between motivational and pedagogical constructs. Specifically, the participating science teachers predominantly exhibited an understanding of knowledge accumulation concerning scientific knowledge and science learning. This typology of epistemic cognition is evident in their metaphors, particularly those describing their epistemic cognitions related to science concepts and science teaching. In Table 5, within the pedagogical construct, the participants generated metaphors related to learning, such as cognitive load (science learning), massive (science concepts), and pedagogical cognitive load (science teaching). These metaphors suggest that the participants' epistemic cognitions regarding scientific knowledge influenced their understanding of the other aspects of their profession. This may be attributed to the curricular design and policies implemented in Turkish elementary and middle schools. Comparative studies have indicated that the curricula implemented in Turkey's elementary and middle schools are more extensive than in other countries (Elmas et al., 2020).

Furthermore, as noted by Soysal (2022) and Aydin et al. (2022), the current 3rd–8th grade science curricula in Turkey encompass five major science subject areas (physics, biology, chemistry, earth sciences, and astrophysics) that need to be taught. The Soysal (2022) concluded that the science topics and practices addressed in the 3rd–8th grade curricula impose a heavy workload, as the participating science teachers perceive. Consequently, the demanding requirements of the overloaded curricula may shape the teachers' epistemic cognitions, leading to the identification of specific metaphorical discourses such as cognitive load, massive, and pedagogical cognitive load. This study demonstrates that epistemic cognition is a complex construct significantly influenced by the educational context within which the participating teachers are deeply immersed (Chinn et al., 2011, 2014).

Table 5 reveals that the participant teachers expressed their metaphorical discourses in three sections: science learning, science concepts, and science teaching, aligning with the pedagogical construct higher-order theme. The participants believed science learning involved the sense-making of natural phenomena (Table 5). Conversely, the metaphors generated for science teaching conveyed the participants' perception that it should include knowledge transmission through instructional modes (Table 5). Consequently, it can be inferred that the participants held a constructivist perspective on learning (meaning-making theme) and a conventional understanding of science teaching (transferring theme). According to educational psychology and learning sciences, there should be consistency between individuals' beliefs about how learning occurs and how instructional activities are implemented in the classroom (Soysal & Radmard, 2018). In other words, one's beliefs about science learning can provide insight into one's orientation toward science teaching. However, as evident in the present study, the participants exhibited ambiguous metaphorical reflections regarding their orientations toward science learning and teaching. This dichotomy may stem from the participants' epistemic cognitions expressed in the sections related to scientific knowledge and science learning. As mentioned earlier, cognitive load, massive, and pedagogical cognitive load emerged as conceptual themes within the science learning, science concepts, and science teaching sections. In essence, the participants perceived scientific knowledge as an endless accumulation, leading to the notion that teaching and learning it would be challenging in the science classroom. Consequently, this kind of epistemic cognition, viewing scientific knowledge as an endless accumulation, might create pedagogical tension for science teachers as they navigate between constructivist and traditional approaches to teaching and learning science.

Overall, this study suggests that the epistemic cognitions of the participant teachers regarding scientific knowledge and science learning concepts may play a determining role in their pedagogical decision-making, which can sometimes be unclear. Furthermore, the participants appeared to oscillate between two conflicting paradigms of science teaching and learning, as reflected in the metaphors generated under the science teaching and science learning sections. Table 5 illustrates contrasting metaphorical expressions within these sections, including meaning-making, transferring, preparing students for daily life, and guiding. These themes are likely influenced by the participants' epistemic cognitions related to the concept of scientific knowledge. As mentioned earlier, the metaphors used by the participants to describe scientific knowledge predominantly reflect an instrumentalist epistemic cognition (e.g., preparing students for daily life) and the perception of scientific knowledge as an endless accumulation (e.g., transferring). These two prominent themes profoundly influence the participant teachers' understanding of science learning and teaching, supported by previous research investigating the connection between epistemic cognition, learning, and teaching (e.g., Suh et al., 2022).

It is worth noting that the participants did not generate any metaphors related explicitly to the pedagogical construct of scientific knowledge. As mentioned earlier, this observation was particularly highlighted during the member-checking interviews with 49 participant teachers. During the member-checking process, the participants were encouraged to provide insights into why they did not perceive an implicit or explicit connection between the concept of scientific knowledge and the higher-order theme of the pedagogical construct (Table 5), as evident from the analyzed data. The responses gathered from the participants revolved around two key themes: (i) the teaching of scientific knowledge in various forms of knowledge and (ii) the distinction between teaching science concepts and teaching scientific knowledge at the elementary or middle school levels, as students are not producers of scientific knowledge. The first point seems to reflect the construction of pedagogical content knowledge (PCK) for teaching science at the elementary/middle school level. PCK for teaching science entails science teachers transforming social languages, jargon, and thinking/reasoning practices into the language and thinking strategies used in the school science context (Kutluca, 2021). This enhances students' understanding of science content and topics while accounting for individual differences (Kutluca, 2021). In other words, the participant teachers claimed that in the science classroom, scientific knowledge is taught in a format that is more accessible for students, as it is transformed into teachable components to facilitate their meaningful learning of scientific knowledge (as indicated by the direct quotation from Milena).

> Milena: The reason for this may be... Well... We have a curriculum. It's a curriculum we must implement and follow. Here, we convey the knowledge to be taught to students differently. For example, by connecting it to daily life. By following different strategies. By playing games, for instance. In other words, we do not explain the direct content to the student encyclopedically. For example, the student has heard a term before, but the term becomes meaningful with activities in the classroom.

In the second theme, during the member-checking interviews, the science teachers explicitly stated that they do not teach scientific knowledge in the science classroom. Instead, they indicated that their role is to teach the science community's knowledge to their students implicitly. The teachers acknowledged that professional scientists primarily generate scientific knowledge, and they facilitate students' engagement in in-class activities that simulate the knowledge-building process of the scientific community in an imitation format (see the direct quotation from Eduardo below). In other words, students participate in activities that imitate knowledge-building processes in science, allowing them to learn science concepts. However, this does not involve the creation of new scientific knowledge; instead, it consists of developing novel or extended individual mental schemes/models that enhance students' explanatory power in understanding natural phenomena, surpassing their existing knowledge. The participants' perspective, as expressed by the science teachers, sheds light on the absence of a direct tangible connection in their epistemic cognitions between scientific knowledge and the pedagogical construct (Table 5).

> Eduardo: Scientific knowledge is not such an easily accessible thing. For example, if you have a disease… You are browsing the internet to find out what the disease is. But when you read, for example, medical journals, you will not understand anything. But if you read from popular internet sites, you will get information about the disease. In the classroom, for example, while children are experimenting, I do not expect them to perform experiments to perfection. They can also make mistakes because they don't have tools like scientists. Their experiments are just simple and primitive versions of what scientists do. But if they go further and do a master's or doctorate after university, they will also work like scientists. I always say this in class.

This issue is a matter of concern within the science education community. Penuel and Furtak (2019) raised questions about how we perceive students in the science classroom:

as learners, producers of science (knowledge), consumers of (science) knowledge, or imitators. On the one hand, there is recognition that students can be viewed as producers of knowledge (Hammer & Manz, 2019; Parsons, 2019), yet this perspective was not evident in the metaphorical expressions of the participant teachers. On the other hand, in the science classroom, students need guidance in developing their scientific knowledge and epistemic practices, which involve rehearsals or imitations of the cognitive, practical, and epistemic endeavors observed within the scientific community (Osborne, 2019). As a note, Osborne's perspective seemed to be held by the participating teachers of the present study. This viewpoint also raises the question of whether the work of scientists within professional communities and students' work in the science classroom are distinct actions (Parson, 2019; Hammer & Manz, 2019). If this is indeed the case, it may explain why the participant teachers did not establish a concrete connection between scientific knowledge and the pedagogical construct (Table 5) in the context of this study. Osborne (2019) also suggests that students' common-sense reasoning is not necessarily aligned with scientifically accepted explanations. This perspective emerged clearly during the member-checking interviews, as the participant teachers did not perceive a resemblance between the work of professional scientists in the laboratory and their students' work in the science classroom or school lab.

Consequently, it implies that canonical science knowledge and students' common-sense reasoning are distinct. Therefore, science teachers are tasked with introducing canonical science knowledge to students as a plausible explanatory system (Osborne, 2019) (this view was reflected in the transferring theme under the science teaching section, Table 5). The current study demonstrates that the participant teachers' epistemic cognitions, particularly related to scientific knowledge, significantly influence their orientations toward teaching and learning science (Suh et al., 2022).

7 Conclusions, Educational Implications, and Limitations

One of the most salient conclusions of the present study is that the science teachers' epistemic cognitions were embedded or situated in the (educational) social contexts in which they carried out science lessons at the elementary and middle school levels. This infers that a naturalized perspective was pervasive in shaping their epistemic cognition. As discussed above, naturalized epistemic cognition is an approach that integrates both the cognitive and social aspects of understanding what-aspects and how-aspects of knowledge, knowledge acquisition, and its teaching. As seen in the metaphorical representations of the participating teachers, they focused on the contextual or situated nature of knowledge, recognizing that cultural, social, and historical happenings influence it. For instance, in building their epistemic cognitions, the participating teachers made direct attributions to their educational environment as this acknowledges that epistemic cognition is not solely an internal, individual process but is shaped by external factors and sociocultural contexts. For instance, in Table 5, in the pedagogical construct line and within the science concepts section, the teachers produced metaphors under the holistic conceptual theme (see also Table 3 for detailed explanations). By advocating that science concepts are holistic, the participating teachers implied that they teach science concepts by considering their internal integration or cohesiveness (e.g., DNA metaphor or tiny puzzle papers metaphor, Table 3). These versions of the integrated science concepts understanding might stem from the curricular objectives and materials recommended teaching strategies inserted in elementary and middle school science curriculums and teacher training programs the participants were possibly engaged in (Aydin et al., 2022). In addition, in recent years, in the Turkish context, there has been particular attention to the STEM classes and programs in the form of integrated science education (Aydin et al., 2022), which might be deeply experienced by the participating science teachers, and this might guide them to generate metaphors showing that science concepts are holistic. Overall, it is concluded that the participating teachers' naturalized or contextually situated epistemic cognitions were seen in their metaphorical externalizations produced for four terms.

Another prominent conclusion of the present study is that the participating science teachers did not see their students as knowledge builders in the science classroom, as discussed above. As a science teacher educator, my position is contrary to this idea, and students should be seen as knowledge producers in the science classroom (Parson, 2019; Hammer & Manz, 2019; Penuel & Furtak, 2019). To support this, when I focus on the history of science, I can see several serendipity incidents (Copeland, 2019): the discovery of penicillin by Alexander Fleming in 1928, the accidental discovery of X-rays by Wilhelm Conrad Roentgen in 1895 or the discovery of the cosmic microwave background radiation, which provided evidence for the Big Bang theory, was a serendipitous finding. Arno Penzias and Robert Wilson were investigating radio signals in space when they encountered an unexplained noise. After ruling out all potential sources of interference, they concluded that the noise was the remnant radiation from the Big Bang, confirming a fundamental aspect of our understanding of the universe's origins. In addition, the history of science has also witnessed several successes of amateur astronomers who may have the resources and access to advanced equipment like professional astronomers. However, they have still made meaningful contributions to our understanding of planets. Amateur astronomers, as lifelong science learners (Jones et al., 2017), equipped with telescopes of various sizes and their dedication to observing the night sky, have made valuable discoveries and observations. One example is the discovery of comets and asteroids. Amateur astronomers have frequently been the first to spot these celestial objects as they scan the night sky. Their keen observations and reports have led to identifying and tracking numerous comets and asteroids, providing valuable data for further study (Jones et al., 2017).

Serendipitous discoveries often result from scientists being open to unexpected observations or events. When students are encouraged to approach their studies with curiosity and a willingness to explore beyond predefined boundaries, they are more likely to stumble upon novel information and insights. This mindset fosters a proactive role in their learning, contributing to knowledge building (Sumrall et al., 2019). In addition, serendipitous discoveries challenge established theories and notions, requiring scientists to think critically and adapt their understanding of the subject. Students exposed to such examples learn that knowledge is not static and can evolve through unexpected findings. This promotes critical thinking skills and an adaptable mindset among students, essential components of active knowledge construction (Sumrall et al., 2019). Many serendipitous discoveries have led to practical applications and technological advancements. By showcasing these connections between unexpected findings and real-world impact, students can better appreciate the relevance of scientific knowledge. This connection to practical outcomes can motivate students to actively engage in learning, knowing that their contributions may have tangible effects (Sumrall et al., 2019). At least for these reasons, the serendipitous scientific discoveries can be connected to the knowledge-building processes of students as not the knowledge consumers but the knowledge builders.

These or similar interpretations were not embedded in the participating science teachers' metaphorical externalizations; however, I can see elementary or middle school students as knowledge producers based on the above-stated or similar incidents in the history of science. In other words, having theory-laden epistemological and pedagogical cognitions regarding scientific knowledge and how science works refers to a version of teacher noticing in the context of epistemic cognition. Students may not be professional members of scientific communities; however, they are members of knowledge-building classroom communities where very similar activities to scientific communities are handled by students as defined by the epistemic nature of science in the next-generation science standards (Suh et al., 2022, p. 1664). As lifelong science learners, students might be seen as knowledge producers if the participating science teachers were engaged in professional training programs, especially incorporating social negotiations of meanings on history, philosophy, and sociology of sciences. As noted by Matthews (2022), I believe that these (surface) epistemic cognitions of the participants about the concepts regarding their profession do not "arose not from personal inadequacies; individuals are not to blame. There was a systematic disciplinary deficiency. This needs to be addressed by raising the level of philosophical competence in the discipline, beginning with including HPS in teacher education and graduate programs." (p. 1). This study, therefore, strongly suggests that science teachers' epistemic visions/cognitions should be elaborated by including both the history and philosophy of science, as well as the philosophy of education, in science-teacher education programs and education doctoral programs, as also recommended by Matthews (2020, 2022). However, before this inclusion, the science teacher educator community takes preliminary actions by locating history, philosophy, and sociology of science in their agenda since this is not a part of the education researcher's repertoire (Matthews, 2022). Overall, this might be the fundamental barrier to training elementary and middle school science teachers holding broader epistemic cognitions by using examples, discourses, narratives, and interpretations from the history, philosophy, and sociology of science to make sense of their profession's four concepts.

As a final note, further points regarding the researcher were declared herein to reference the reflexivity in this descriptive study where primarily interpretive paradigm's thinking styles were operated. This clarification is pivotal as one's metaphorical externalization becomes intricately entwined with the social context, shaping one's construction of reality, particularly in exploring the four concepts under investigation. It is imperative to note that the acknowledgment of this aspect does not denote a limitation of the study but rather an acceptance that the researcher might carry biases and conceptual constraints when understanding and reinterpreting individualized or private mental frameworks, such as metaphorical externalizations, as epistemic cognitions. Within the confines of this study, the researcher demonstrated cognizance of his academic and intellectual background, beliefs, values, and experiences concerning the four concepts explored. These elements played a pivotal role in shaping the trajectory of data collection, analysis, interpretation, and reporting without constraining the study's scope. While the researcher's societal connections with the participants contributed to interpreting analytical codes, conceptual themes, and meta-themes (see Table 1, 2, 3, 4, and 5), it simultaneously presented a challenge due to the inherent lack of a neutral conceptual standpoint. An illustrative instance lies in certain phases of data analysis where the researcher continually questioned why science teachers, despite national initiatives favoring student-centered science teaching approaches, clung to teacher-centered epistemic cognitions. To navigate these challenges, the researcher diligently employed coping strategies for conceptual biases, such as member checking, bolstered analysis capacities through external audits, and assumed neutral meaning positions by consciously bracketing preconceived notions and biases during data collection and analysis. These efforts were undertaken to augment the study's findings' rigor, transparency, and validity.

Appendix. The metaphor construction task.

The purpose of the study: The purpose of the study is described herein
Participant consent: The participants signed the consent form in this phase
Video link: The 4-min video link is inserted herein

How would you describe **scientific knowledge** using a metaphor?
Can you think of a metaphor that represents your experience of **scientific knowledge**?
Your metaphor:

Explanation/justification:

How would you describe **science learning** using a metaphor? Can you think of a metaphor that represents your experience of **science learning**?
Your metaphor:

Explanation/justification:

How would you describe **science concepts** using a metaphor? Can you think of a metaphor that represents your experience of **science concepts**?
Your metaphor:

Explanation/justification:

How would you describe **science teaching** using a metaphor? Can you think of a metaphor that represents your experience of **science teaching**?
Your metaphor:

Explanation/justification:

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Data Availability The study participants did not give written consent for their data to be shared publicly, so supporting data is unavailable due to the research's sensitive nature.

Declarations

Conflict of Interest The author declares no conflict of interest.

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