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Epistemological beliefs and classroom practices of experienced physics teachers: are they related?

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There is a need in teacher education to explore experienced physics teachers' domain-general epistemological beliefs and classroom practices. The study reports 30 experienced physics teachers' epistemological beliefs and classroom practices in Turkish public high school context. The data was collected through interviews and classroom observations. During the analysis, qualitative data was analyzed through constant comparative method. Level and frequency of participants' epistemological beliefs and classroom practices were quantified for descriptive statistics. The results indicated that most teachers held transitional epistemological beliefs, but they taught in traditional ways. Their epistemological beliefs and classroom practices were not in alignment. These results showed that experienced teachers might have sophisticated epistemological beliefs, but they were not able to reflect their beliefs into practice according to their perception of students' expectations. The study provides implications for research for teacher learning and development through large-scale longitudinal studies and to understand the factors of misalignment between their beliefs and practices.

KEYWORDS

belief, epistemology, experienced, in-service teacher, physics, practice

1 Introduction

Professional development to address science teachers' beliefs and practices aims to enhance their orientations toward constructivist teaching and learning (Sengul et al., 2021; Enderle et al., 2022). Constructivism is interested in the construction of knowledge through relating existing knowledge with new knowledge by discovery and inquiry to enhance students' active participation and ownership of their learning process (Bybee, 2010). Constructivist instruction aims students to construct or invent the meaning and relations of conceptions through diverse interactions and experiences. This process helps students understand the tentative nature of knowledge that change through inquiry including research, experiments, and observations.

Recent reforms in science education (NGSS Lead States, 2013) suggest that students need to take an active role to develop competence to understand and apply scientific practices within the learning processes. Science teachers have an important role in the development of scientific literacy. The Organization for Economic Cooperation and Development (OECD) by means of the Program for International Student Assessment (PISA) suggests that reform-based standards in most countries (USA, UK, Japan, Turkey etc.) aim to develop teachers' capacity to promote knowledge construction, critique, and re-evaluation of diverse claims through authentic science activities to develop evidence-based scientific explanations (Ford, 2015; Henderson et al., 2015). Reform-based science education also aims to enhance students' capacity to develop critical thinking, decision-making, and communication skills in a scientific way while developing the science content knowledge. Learning occurs through active participation by asking questions, data collection and analysis through experimentation, constructing explanations, and making connections to real-life events (Schwab, 1966). However, most science teachers tend to believe that science should be learned through memorizing the relevant vocabulary, proving formulations via experimentation, and direct instruction among students with similar abilities (Banilower et al., 2018).

Teacher beliefs can act as a filter or facilitating construct to frame science teachers' practices (Kang and Wallace, 2005; Sengul et al., 2020). These previous research examined the relationship between teachers' beliefs and practices. These studies investigated that science teachers' beliefs about teaching and learning science were not related to teachers' practices. Therefore, the current study attempted to address a gap in the literature to explore how physics teachers' epistemological beliefs as domain-general beliefs related to their classroom practices. This study can complement the literature through focusing on beliefs and practices from an epistemological perspective.

2 Theoretical perspectives

2.1 Teaching and learning in science education

Inquiry-oriented instruction aims to engage students in twenty first century skills to adapt to new situations, collaborate with peers, communicate in oral and written formats to enhance critical and logical thinking skills (Partnership for 21st Century Skills, 2016). This learning approach addresses students' diverse needs and prior conceptions to promote students' active participation in doing science activities and solving problems and communicate their findings with peers to resolve the inconsistencies. Constructivism has a major theoretical influence in science education and suggests that learners should actively construct knowledge, and constructed knowledge may change via variable interpretations of their experiences (Matthews, 2002). In addition, Vygotsky and Cole (1978) supports that knowledge construction occurs through social interaction or by the guidance of an expert or a teacher through scaffolding. Recent discussions on scientific literacy supports constructivism to emphasize the scientific practices that learners should engage in such as conducting scientific investigations or engaging in argumentation to have meaningful science learning experiences (Schwartz et al., 2023).

Dewey (1910) argues that science should be taught as a way of thinking or as a way of process. Science teaching and learning are suggested to construct knowledge through "hands-on" and "minds-on" activities. As suggested by Schwab (1966), learners should work in laboratory settings through generating their own questions, gathering evidence, and providing explanations based on their investigation. A Framework for K-12 science education (National Research Council, 2012) addresses common inquiry activities as follows: (1) focusing on scientifically oriented questions and problem-solving, (2) data collection and analysis, (3) constructing evidence-based explanations, (4) justifying scientific explanations with theory, laws, and models, and (5) communicating information in diverse literacy modes- oral, written or spoken. These standards suggest that the role of the teacher is to facilitate the learning process with guiding, motivating, and challenging activities and questions. Teachers should support the learning process to increase students' participation in active learning through inquiry through combining different teaching strategies and diverse assessment methods.

2.2 Epistemological beliefs

Henry (1969) defined knowledge as infallible related to understanding of a certain fact or cause-and-effect relationships to infer and reason about cognitive domain, but definition of belief was considered as fallible, indirect, and questionable about affective domain. Fives and Buehl (2012) approached this definition from a different perspective to explain how individuals perceived things through their belief systems, and beliefs could serve as a filter or evoke to shape teachers' actions, goals, and practices. Domain-general epistemological beliefs aimed to address personal beliefs about nature of knowledge and knowing (Hofer, 2010). In science education literature, teachers' and their students' epistemological beliefs have been explored to enhance the quality of teaching and learning process through reform-based strategies (Suh et al., 2022). This process aimed to involve learners in scientists' practices to learn through the habits of mind-thinking through how and why (Chinn et al., 2011). Researchers aimed to improve learners' domain-general epistemological beliefs through social interaction and diverse reasoning processes to argue from evidence.

Epistemological beliefs include developmental and multidimensional characteristics. Developmental views of epistemological beliefs defined a unidimensional or stage-like structure that developed in phases from absolutism to evaluativism (Kuhn, 1991). The most mature or sophisticated beliefs defined knowledge construction and modification based on evidence in an iterative process, whereas premature epistemological beliefs were considered as related to surface-level of learning through naïve, certain, and simple knowledge (Brownlee et al., 2017). Research on epistemological beliefs from a developmental perspective (e.g., Perry, 1970; Belenky et al., 1986; King and Kitchener, 1994) supported the research on epistemological beliefs from a multidimensional perspective. Schommer (1990) started the discussions on multidimensionality as a system of dimensions referring to certainty, simplicity of knowledge, control and speed of learning and the source of knowledge. Hofer (2001) modified the dimensions and included justification of knowledge dimension. Wood and Kardash (2002) determined differently named independent dimensions: speed of knowledge acquisition, structure of knowledge, knowledge construction and modification, characteristics of successful students, and attainability of objective truth.

Very little has been known about how in-service teachers' domain-general epistemological beliefs impact their teaching since most research has been conducted on pre-service teachers' epistemology (Chan and Elliot, 2004; Lee et al., 2012). These studies approached epistemological beliefs considering the effects of social and cultural contextual issues (Hofer, 2010). For example, Lee et al. (2012) conducted a study to compare the epistemological beliefs of Chinese pre-service teachers from three different countries, Taiwan, Singapore, and China. A survey was applied to assess participating pre-service teachers' beliefs about nature of knowledge and knowing. Based on the sociopolitical differences, students from Taiwan and Singapore had more mature epistemological beliefs, whereas students from China possessed mixed views about knowledge. In terms of innate ability, Taiwanese students believed the effect of nature characteristics on learning even though other students did not value innate ability too much. In another study, Brownlee et al. (2010) worked with teachers of children in Australia to understand how teachers' beliefs about knowledge and knowing influenced their personal and social communication. Their results indicated that social relationships had control on teachers' personal decisions and development of their identity. Brownlee et al. (2011) also worked with pre-service teachers of early year students, who attended a course on critical thinking. The results showed that student teachers advanced their beliefs about integrated knowledge, quick knowledge, innate ability, and knowledge construction; but they were not able to improve their beliefs about certainty and source of knowledge.

Teachers may frame their teaching according to learning situation or context in the classroom. Russ and Luna (2013) argued that according to constructivist epistemological framing, a science teacher could guide students to plan and investigate to collect and analyze data and make explanations. Teacher's epistemological framing could support the classroom context to socialize and work in a dynamic process. Working with in-service teachers with various teaching experiences, Bendixen and Corkhill (2011) showed that experienced teachers possessed more sophisticated beliefs about certain and simple knowledge and beliefs about innate knowledge than less experienced teachers. Design of these studies suggested that research on in-service teachers should be conducted to investigate their existing epistemological beliefs and to plan future professional development programs. Therefore, the current study aimed to explore experienced in-service physics teachers' epistemological beliefs in relation to their teaching practices in Turkey.

2.3 How do classroom practices relate to teachers' epistemology?

In teacher education, it is important to understand teachers' epistemological beliefs to plan their development and improve their teaching practices, and teacher epistemology has been rarely studied in related to their practices (Sengul et al., 2020; Dai, 2023). Domain-general epistemological beliefs can give insights about teachers' perceptions, teaching goals, and views of nature of discipline (Sinatra, 2016). Teachers are expected to develop reform-based teacher identity to integrate performance and content standards to apply scientific inquiry. For example, Sengul et al. (2020) explored the relationship between science teachers' domain-general epistemological beliefs and teaching strategies. The results showed that mature epistemological understandings tended to facilitate argumentation instruction to support students' discursive dialogues, but mixed epistemological understandings tended to modify the inquiry activities to integrate more didactive approach. In addition, Dai (2023) argued that epistemological differences in teachers and scientists might lead to their engagement in interactions in different ways. The study indicated that teachers preferred easier interactions through filtering to consult or reject ideas related to teaching practices, but scientists tended to emphasize the scientific inquiry through negotiation of knowledge claims to construct knowledge. Yang et al. (2008) worked with in-service secondary earth science teachers to explore their views about the constructivist instruction and epistemological beliefs through surveys. The findings emphasized that teachers' domain-general epistemological beliefs were not sophisticated to align their teaching views with constructivist approach. Teachers with constructivist views aimed to support students' active participation to promote the responsibility of knowledge construction and to enhance motivation. Teachers, who possessed mixed or traditional epistemology, prioritized the national curriculum standards to use alternative methods of instruction although they supported the use of traditional instruction. Although experienced science teachers easily integrated constructivist views into practice in Mansour (2013)'s study, the author also discussed the inconsistency between in-service teachers' epistemological beliefs and practices. Although some teachers viewed student-centered instruction as a valuable practice, their classrooms implementation was teacher-centered. The author found that contextual factors were effective on this inconsistency such as administrative pressures, students' ability, time, resources, and subject matter knowledge. These factors had a negative impact on the integration of teachers' beliefs into their practices.

2.4 Present study with research questions

The literature review revealed that there were consistency and inconsistency between teachers' epistemological beliefs and practices in different contexts such as China or Australia. This study aimed to explore experienced physics teachers' epistemological beliefs and instructional practices in Turkey as a different educational context. The study was framed in the context of Turkish public high schools where students had high science and mathematics background. The study aimed to address the following research questions:

1. What are expert physics teachers' epistemological beliefs?
2. What teaching strategies do expert physics teachers use in their classrooms?
3. How do experienced physics teachers' epistemological beliefs relate to their classroom practices?

3 Methodology

3.1 Research design

The study had a mixed-method design that included quantitative and qualitative strands to answer the research questions (Creswell and Clark, 2011). The quantitative and qualitative strands occurred sequentially or independently to address distinct research questions (first and second research questions); but comprehensive interpretation of results is done to answer the third research question (Creswell and Clark, 2011). As to the relative importance of two strands within the design, this study made use of qualitative data primarily including interviews; quantitative aspect of the study included classroom observations and quantitative coding of participants' views of inquiry. Qualitative data and quantitative data were utilized to support and triangulate the findings.

3.2 Participants

Thirty physics teachers from Turkish public high schools accepted to participate in the study voluntarily. These teachers were selected conveniently and purposefully from a metropolitan city of Turkey, where the researchers' university was located. Ten of the participants were women, and twenty of the participants were men with more than 10 years of experience in teaching physics; the participants' ages ranged from early 30's to 60's. These teachers were teaching at the science high schools and Anatolian high schools as project schools where highly motivated students could attend to study science and mathematics with enough middle school grades and exam scores. The students in other school types such as vocational and technical Anatolian high schools, religion-based Anatolian high schools, social science, fine arts, and sports high schools tended to have low mathematics and science background and select a specialization parallel to their schools' intent. Science and Anatolian high schools constituted a larger school category in student population than other types of schools, so the participating physics teachers were selected from these two categories.

There were two types of educational background: 18 physics teachers (16 male, 2 female) attended a physics department in one of Turkish University's Faculty of Science and took educational courses to receive pedagogical certificate. Students from physics departments could take additional educational courses for 1 year when they were in the program to learn about teaching approaches. Fourteen of the teachers (6 male, 8 female) attended a teaching physics program in one of Turkish University's Faculty of Education to get a diploma accounted for teaching physics. Teaching science or physics courses in the faculty of education addressed the implementation of inquiry-based instruction for students' learning needs. After their graduation from the university, only a few teachers participated in the graduate school for professional development on teaching through inquiry (two teachers) or teaching physics content (4 teachers). One teacher received certificate on curriculum development for inquiry activities, another teacher attended a master program on instructional approaches, and two physics teachers were continuing a doctorate degree in a physics department, and two other physics teachers completed master's degree on physics engineering. The details for demographic information are presented on Table 1. All the lessons were taught in Turkish (in the mother language of the country).

3.3 Data collection and analysis

This study utilized multiple data sources to understand participating physics teachers' epistemological beliefs and instructional practices in teaching physics. These data sources were semi-structured interviews' verbatim transcriptions and researchers' field notes from classroom observations. The classroom observations were conducted at different time points of the year while teachers were teaching different topics.

3.3.1 Semi-structured interviews

The researcher conducted one semi-structured interview with each physics teacher at their school. Each interview lasted about 1 h and was conducted by the OS. These interviews aimed to address participants' epistemological beliefs, so participants were asked open-ended questions focusing on their beliefs. The interview questions modified from Brownlee (2003) and Chan and Elliot (2004). The interviews included following sample questions and sub questions:

- How does knowledge in physics develop?
    - What is knowledge? Could you explain where your knowledge comes from?
    - What do scientists do or how do scientists work to develop knowledge?
    - Does scientific knowledge involve facts or opinions or both?
- Do you think that learning depends on natural abilities or hard work? What does learning depend on?
    - How do you know when you or your students know something?
    - What are your views in learning about something you really want to know?
- How does learning occur? Does learning occur quickly or require time?
    - When do students tend to memorize to do physics well?
- Does science knowledge involve complexity for humans' understanding?
- How does our knowledge of physics develop via authorities or through self-construction?
    - A physics teacher says something is a truth. Is it true or wrong? Please explain.

To understand experienced physics teachers' epistemological views, the study did not focus on the changes in their epistemological beliefs. These questions aimed to elicit participants' epistemological beliefs at the time of the study.

The interviews were transcribed verbatim to conduct open coding and selective coding to determine teachers' epistemological beliefs at different complexities. Corbin and Strauss (2008)'s constant comparative method was utilized to understand the

TABLE 1 Experienced physics teachers' demographic information.

Educational experiences	Participants #	Teaching experiences (years)	Male	Female
Physics + Pedagogical formation	12	12 - 33	11	1
Physics + Pedagogical formation + doctoral degree	2	21 - 24	2	-
Physics + Pedagogical formation + master's degree	2	27 - 30	2	-
Teaching Physics	12	11 - 33	6	6
Teaching Physics + master's degree	2	11 - 27	-	2

TABLE 2 Definitions for dimensions of epistemological beliefs.

Category	Definition- naïve views
Certain knowledge	Knowledge is certain and does not change.
Innate ability	Learning requires innate ability rather than hard work or effort.
Source of knowledge	Knowledge sources depend on the authority as a person or a book rather than self-construction.
Quick knowledge	Learning occurs at the first time of reading or taking a course, otherwise learning does not occur.
Simple knowledge	Knowledge does not involve complex or integrated structures; knowledge should be as simple as possible.

themes across different physics teachers' epistemologies. Teachers' epistemological beliefs were coded and categorized based on the common dimensions suggested by Schommer (1990) and Hofer (2004). These categories are presented on Table 2 with definitions. After teachers' views were assigned as a code during the first phase of the analysis; in the second phase, codes were categorized into three distinct levels based on the complexity as traditional, transitional, and constructivist. These levels were modified from Muis (2004) where traditional beliefs focused on teaching science as certain facts, transitional beliefs emphasized the alternative ways or methods, and constructivist beliefs defined knowledge as tentative, evolving, and based on evidence-based explanations through exploration. In the third phase of the analysis, the levels for teachers' epistemology were quantified as traditional (1), transitional (2), and constructivist (3) for quantitative analysis. A moderate interrater reliability (70%) for quantitative coding was established by two raters for teachers' epistemological beliefs at different dimensions; disagreements were discussed to establish higher consistency across the raters for final analysis. After categorizing epistemological beliefs, participating physics teachers' interview responses were utilized to construct a holistic belief profile. Teachers' similar responses were classified under the dimensions of epistemological beliefs. Excerpts were provided for illustration of each dimension for constructivist, transitional, and traditional levels.

3.3.2 Classroom observation

The researcher conducted 40 classroom hours of observation in 30 participants' physics lessons on various topics. The time of each observation was arranged according to teachers' schedule. The classroom observations were conducted via taking field notes by the first author. The field notes included dimensions of teaching practices including instructional strategies, content knowledge, classroom discourse and interaction, and use of technology. These codes were developed through constant comparative method (Corbin and Strauss, 2008) to develop data-driven and theory-driven codes and categories in developing themes as dimensions of physics teachers' classroom practices. Theory-driven codes were used from three observation protocols: Classroom Observation Protocol (COP) (Lawrenz et al., 2002), Teaching Dimensions Observation Protocol (TDOP) (Hora et al., 2013) and Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002). The first author developed codes on the main elements of classroom instruction, and these codes were utilized for training a graduate student in coding online training videos and field notes to score and have discussions on scoring. Both researchers analyzed 33% (10 teachers) of classroom observations to code and compare the results. The first author discussed the coding process with the graduate student to understand the consistency across observations. Interrater reliability was found at 90% across teachers' implementations between the raters. The observation scores were presented through descriptive statistics in the results section. The levels for teachers' teaching approaches were categorized as traditional (1), transitional (2), and constructivist (3) for quantitative analysis. One-way of teaching process such as lecturing with teachers' problem solution was considered as a traditional instruction; teachers' integration of daily life examples to enhance student participation was considered as a transitional practice; and teachers' use of laboratory or small-group activity with interactive discussion among students and between students-teacher was considered as a constructivist approach (Tsai, 2007). As Mansour (2013) suggested, the practice could be defined as constructivist, transitional, or traditional teaching if the percentages of the codes were highest in those categories. For example, a participant, who scored more than 50% in the teacher-centered instruction, was categorized as traditional, but another participant was categorized as transitional if he/she scored more than 50% in valuing students' participation through problem-solving and modeling. The relationship between teachers' epistemological beliefs and their classroom practices was interpreted in a continuum for comparison.

4 Results

4.1 Expert physics teachers' epistemological beliefs

This study revealed experienced physics teachers' domain-general epistemological beliefs in different dimensions: certain knowledge, innate ability, source of knowledge, quick knowledge, and simple knowledge. Table 3 presents the participating teachers' constructivist, transitional, and traditional views on these dimensions. In terms of certain knowledge, most teachers held constructivist beliefs that knowledge was modified and generated through new evidence from exploration and experimentation. Some teachers indicated transitional beliefs that people might approach things in diverse ways, whereas four teachers supported the use of textbook to memorize information from a traditional approach. Excerpts from the individual interviews were provided below for each level:

Interviewer: How does knowledge in physics develop? What do scientists do or how do scientists work to develop knowledge?

Teacher-9: To some extent, learning is like a juxtaposition of small memorizations. Learning is the memorization by establishing a connection. For example, 7 × 8 is 56, it's more like "where is this going to be used?" In other words, it would be better if 56 was known where and in which process it should be used. Therefore, it is necessary to memorize it first. (Traditional)

Teacher-1: People should not look at everything in the same way... Things should not be looked at that way in the way that normal ordinary people do. (Transitional)

Teacher-6: Physics is trying to find something and prove it, trying to explain it with mathematical methods and equations. (Transitional)

Teacher-8: Researching from the right sources, reliable sources, questioning, researching from more than one source. Not to go directly to google and say, "What happened about this?" "What is written on Wikipedia?" from the internet and get any information, but to get academic studies on the subject, studies done by scientists. Knowledge is a product of the work done from the past to the present…Even the things that we say are very valid today… More recently, the Nobel Prize in physics was awarded on Quantum Entanglement. In other words, you know that many things that we think are right are maybe wrong, or that something we think is wrong is true, there are no absolute truths, in this sense, knowledge can also change and develop. (Constructivist)

In these statements, traditional views emphasized that textbooks included absolute truths and accumulated facts for memorization. These teachers believed that scientific theories and laws should be well-stated in textbooks as universal knowledge to memorize. Transitional views addressed that knowledge development required individual perspectives and meaning-making through curiosity, need, and interest. These teachers thought that scientific knowledge developed through mathematical modeling and verification following the scientific methods. Constructivist views emphasized that knowledge could change through research, exploration, and integration to evaluate new findings. This process required individuals to think critically by using reliable sources and careful research to reach a product of a process to search and develop a capacity.

In terms of innate ability, participating teachers had diverse epistemological approaches. Teachers with traditional epistemology suggested that learning occurred through repetition and memorization without requiring prior knowledge. These teachers did not talk about the natural characteristics of human beings in the learning process. Teachers with transitional beliefs believed that people had nature abilities which could develop in different ways due to context, prior knowledge, and curiosity. Teachers with constructivist beliefs indicated that people learned through integrating theory into experiments by hard work, perseverance, and logic. Table 3 presents the participating teachers' constructivist, transitional, and traditional views on innate ability. Excerpts from the individual interviews were provided below for each dimension:

Interviewer: Do you think that learning depends on natural abilities or hard work? What does learning depend on?

Teacher-21: The student must have a mathematics ability. If students have a poor math ability, they have some difficulty in learning physics because in physics, you know, they need to use mathematics to solve problems, and students who have trouble with mathematics. (Traditional)

Teacher-1: The student may not be able to do physics, but he can do something… Intelligence can be at a certain level; but if you give, to a greater or lesser extent, anyone can learn physics. You can learn it in the cinema, you can learn it on television, you can learn it in commercials. You can learn from any area of life. You don't know how to find out. (Transitional)

Teacher-3: Students should be curious. They should have a dream and a goal. These students should want to do something in life. In other words, a good student wants to come somewhere, wants to do something, and wants to make a production. These high-achieving students in physics (1) they repeat, repeating is an important thing, repeating makes a habit (2) they read good books, reading books is extremely important. (Transitional)

Teacher-5: If they see physics as a way of life rather than a lesson, they will perceive it much more easily. In philosophy, you need to teach thinking, the student who thinks does physics. Creativity comes out. They can discover on their own, without me telling them, how to boil water at 40 degrees. Of course, they know, they do research, but the aim is to research and learn by researching. (Constructivist)

In these statements, participating traditional teachers emphasized the significance of repetition in different intervals to be successful in physics. They did not address the value of prior knowledge since they thought that individuals could learn through their natural abilities. Teachers with transitional beliefs indicated that students could be successful through developing interests and imagination and believing in their capability at least on one area since they might have diverse abilities and prior knowledge in different areas. These teachers believed that individuals could be successful with average innate ability to develop good study habits. Constructivist teachers suggested that people could engage in problem-solving practices through application and integration of

TABLE 3 Participating teachers' epistemological beliefs at different dimensions.

Beliefs about	Statements	Teachers	
		#	%
Certain knowledge	Textbooks include accumulated facts for memorization[a]	4	13
	People may perceive things differently[b]	4	13
	There is no absolute truth[b]	2	7
	Knowledge requires curiosity and interest[b]	4	13
	Science verifies laws and theories through mathematical modeling[b]	4	13
	Scientific knowledge is changed and constructed through findings of exploration and experimentation[c]	14	47
	Knowledge generation requires analytical thinking[c]	2	7
Innate ability	People learn through repetition and memorization[a]	1	3.3
	Learning does not require prior knowledge[a]	1	3.3
	People have nature abilities, but can develop in different ways due to context, prior knowledge and curiosity[b]	14	47
	People learn through integrating theory into experiments by hard work, perseverance, and logic[c]	14	47
Source of knowledge	Students should use textbooks, private tutors, and internet resources[a]	12	40
	Teachers should act as the authority[a]	5	16
	Knowledge comes from nature or daily life through observation[b]	9	30
	Student learning is influenced by instructional strategies and assessment methods[b]	9	30
	Sociocultural factors cannot influence the knowledge production[b]	5	16
	Parents control students' learning[b]	5	16
	Knowledge is generated in diverse ways: questions, experiments, projects, collaboration[c]	11	37
	Sociocultural factors influence the knowledge development[c]	4	13
	Student learning should be independent from an authority[c]	1	3
Quick knowledge	Learning occurs easily through lecturing, memorizing, and providing short and practical solutions[a]	4	13
	Good students tend to listen and take notes carefully to ask good questions[a]	2	7
	Learning occurs by changing experiences, behaviors and thoughts in time[b]	4	13
	Mathematics and technology provide quick modeling approach for science concepts[b]	7	23
	Teachers may need to explain a topic in different and several ways[b]	2	7
	Curriculum should support discovery to enhance learners' critical thinking[c]	7	23
	Learning requires patience to make sense of problems[c]	6	20
	Students should evaluate concepts and their observations[c]	1	3
Simple knowledge	Experts should be organized[a]	1	3
	Knowledge requires diverse and complex experiences or method in creative ways[b]	9	30
	Teachers should solve problems from simple to hard ones[b]	7	23
	Students should be confused about concepts and real-life applications[c]	5	17
	Knowledge develops through large and connected experiments or complex problems in different contexts[c]	9	30
	Physics concepts can be considered as a guide to solve economical and sociological problems[c]	3	10

a, traditional; b, transitional; c, constructivist. Some teachers might state in more than one statement.

theory into practice in different contexts or situation by using hard work and creative thinking skills to ask how and why questions, develop models, design and conduct experiments, and utilize research tools. They believed that learning involved both biologic and environmental processes; and successful people have high curiosity, self-confidence and discipline to use high interpretation and analysis abilities and make cause-and-effect relationships.

In terms of beliefs about source of knowledge, most physics teachers in the traditional category suggested the use of textbooks, private tutors, and internet resources as sources and authority of knowledge. Teachers with transitional beliefs thought that knowledge came from natural and daily life observations, and teachers should support the integration of these observations in the instructional strategies and assessment methods. These teachers added that parents might have a role to facilitate or block students' learning process since they had demands for standardized testing. Constructivist teachers thought that students' learning should be independent from an authority. They added that curriculum should support learning through experimentation, observation, and collaboration activities. However, they emphasized that sociocultural factors might influence the educational system to develop knowledge. Table 3 presents the participating teachers' constructivist, transitional, and traditional views on source of knowledge. Excerpts from the individual interviews were provided below for each dimension:

Interviewer: How does our knowledge of physics develop via authorities or through self-construction?

Teacher-9: In my first 2 years, I solved thousands of questions in the summer. I said that when I go to school, I will not be afraid of any of my students, they can ask questions from anywhere they want, and the first 2 years passed like this... I have a great discipline in this way. I'm telling something valuable in the classroom so that they must listen. I adapt the students to the lesson. (Traditional)

Teacher-30: I like to follow the professors on YouTube or the usually textbook sources to explain their creative power. (Traditional)

Teacher-12: I am exam-oriented, book-oriented, lesson-oriented. I write notes, I research books, for example, when I am talking about a topic, which question should be solved, what should be solved next, what should I solve, where is it here, where is there. (Traditional)

Teacher-4: If the teacher does not just stay as a thing, for example, when teaching a lesson, he only gives a formula - the event is not just solving questions on the formula; It is necessary to explain that it is in all areas of life. (Transitional)

Teacher-10: Of course, the method of explaining electromagnetic theory and the method of teaching a classroom management or a material development course in teaching were not the same. Of course, if the teacher of these courses was the same, we could see totally different teaching methods. I mean, I remember, for example, "Wow, he was a very different teacher here, but he became a completely different person here" or he changed his methods across the concepts. (Transitional)

Teacher-14: Learning takes place through the student's involvement in work. I do homework because there is such a thing, no matter how much we tell him, the brain never encodes the information. It is possible for the brain to encode information by the student taking the question and trying to solve it. In other words, when he starts to work practically, learning takes place. (Constructivist)

Teacher-16: By exemplifying physics education with the event in our daily life, which is not memorized, and this can be done with simulation in practice, but I do not think this is very enough. There would be a laboratory study before the subject we will cover, you need to be prepared before that laboratory work. There were experiments on this, there would be quizzes, oral quizzes during these activities. (Constructivist)

In these statements, traditional beliefs on source of knowledge emphasized the authority of teachers to prepare and solve several types of questions in the classroom; they tended to support the preparation of new textbooks for exam preparation and suggest students to get help from private tutors. These teachers supported the establishment of disciplinary rules to functionalize the authority of the teacher through traditional instruction. They believed that students needed to obey rules by keeping silence and listening to the lectures. However, teachers with transitional epistemology thought that learning physics did not require a classroom context since the topics were related to nature and daily-life issues, and curriculum should integrate discussions related to real-life events. These teachers ignored the influence of beliefs in teaching and learning process and supported the use of different instructional strategies to address prior knowledge. These teachers tended to focus on the theoretical information to utilize textbook, technology and online sources such as simulations for lesson planning. For example, some teachers stated that they used teacher-created notebooks or power point presentations in their classrooms as a guide for students' learning to give homework. They emphasized the communication with parents about students' learning process as a significant factor of students' success. Teachers with constructivist epistemology believed that curriculum should support the knowledge development through application-experimentation and observation via several different sources such as questions, materials and models rather than focusing on plain textbook reading. They suggested that these activities could enhance students' critical thinking, involvement and collaboration for peer instruction to learn from evidence through data collection and analysis. They thought that in this process, student diversity might play a role in shaping the learning progress and addressing their needs.

In terms of quick knowledge, teachers with traditional views believed that learning easily occurred through lecturing and solving problems with short and quick solutions to direct students for memorization. Some teachers argued that good students tend to listen and take notes to access information easily. Other teachers with transitional beliefs thought that learning required making connections to prior experiences to make changes in behaviors and thoughts. Some teachers indicated that mathematics provided quick modeling approach for physics, and teachers could easily change teaching methods through modeling and technology. In the third category, constructivist teachers suggested the inclusion of discovery activities into curriculum and instruction to enhance learners' critical thinking skills. These teachers also believed that learning required patience to make sense of problems and evaluate them toward different solutions. Table 3 presents the participating teachers' constructivist, transitional, and traditional views on quick knowledge. Excerpts from the individual interviews were provided below for each dimension:

Interviewer: How does learning occur? Does learning occur quickly or require time?

Teacher-19: Students can easily learn for testing through lecturing, short solutions, and practical application of problems. (Traditional)

Teacher-1: For things to catch up, there has to be a certain process for a period of time for things to settle down. I've learned that sometimes you have to be very patient. I learned that we should be able to look at things through the eyes of students. It's definitely exhausting, definitely sometimes you don't have patience, even where your patience ends, sometimes we have to show patience. After all, you're dealing with people, that's always going to be a problem. Nothing goes 100% in machine order. Patience is always required. But sometimes we can, sometimes we can't. (Transitional)

Teacher-26: When it is student-centered, we need to constantly add to the student, we need to give homework to the student, we need to give responsibility to the student. For example, we need to say "prepare for this", "you do this", "research what do you think about this," but we don't have much time for them because the curriculum is very intense, we think that we are almost wasting time even when we promise during the student, and we tend to finish the subjects as soon as possible, that is, in that sense. Our situation right now is teacher-centered, not student-centered. (Transitional)

Teacher-10: It is a photograph or video of events in nature that we can or cannot observe. Therefore, in the understanding of the universe, physics is of course a guide for everyone in society as well as individuals. It was built on this foundation. If you want to explain something because of it, you need physics. I pay a lot of attention to the research part and the observation part. When you don't observe, when you don't do research, you can't detect the problem, the problem has to be detected first, and you can't start at all. Therefore, I tell my students to do more research and observation, I want them to observe and research about their environment, about school, when they go to transportation, everywhere, all the time, so that they can see the problems. I pay more attention to this part. Research and observation. (Constructivist)

Teacher-8: The Michelson-Morley experiment is very interesting. I tell the kids, it's an experiment that has lasted for years. When you are trying to prove the existence of something, you are proving that it does not exist. It's also a very interesting experiment. Of course, it also requires effort, perseverance, and patience for so long. I don't know exactly, but as far as I remember, that experiment lasted about 15–20 years. They do it in various parts of the world, they do it here and there in various weather conditions to see if the result will change, but here they see that it does not change. (Constructivist)

In these statements, traditional teachers argued that our education system forced students to memorize, choose one option, and forget. They thought that teachers needed to transfer the information; or in other words, teachers could reach the information and distribute the ready-made information for students who tended to listen and take notes carefully. Transitional teachers thought that people might not be successful to understand the concepts easily, there needed to have a process to experience the change and learning. This process required teachers to be patient and continue teacher learning to follow the new findings in the literature to talk about recent developments by making connection to the prior understandings and daily life examples. Thus, teachers defined knowledge as the theoretical and mathematical presentation of applications that will make human life easier and put our lives in order. Some teachers said that they could teach a concept by solving 20 questions to address different ways to solve problems. Some constructivist teachers suggested that the curriculum should integrate contextual and life-based topics to be able to apply and model different problems using diverse methods. They suggested that individuals need to develop higher order thinking to persevere to achieve without memorization. This might require time and effort to help students ask questions to define problems and find the results by themselves. They suggested that students should be encouraged to discover in a period to investigate and deal with the mechanism to collect and analyze data through changing the parameters.

In terms of simple knowledge, participating teachers with traditional epistemology suggested that experts should be organized and follow step-by-step procedures to find solutions. Transitional teachers believed that knowledge required diverse and complex experiences, so teachers should integrate different type of problems from simple to hard ones. Constructivist teachers supported that teachers should make students confused about the concepts and real-world application through large and connected experiments or complex problems that could cover several topics. These teachers thought that science concepts could be integrated in other sciences to solve economical and sociological problems. Table 3 presents the participating teachers' constructivist, transitional, and traditional views on simple knowledge. Excerpts from the individual interviews were provided below for each dimension:

Interviewer: Does science knowledge involve complexity for humans' understanding?

Teacher-6: In general, people are disorganized, I see it. You know, as in Einstein's photograph, there is usually a mess, but it should be organized, sir. For example, I am very organized. I bought my tablet, searched for a few publications on my tablet, questions and their keys. (Traditional)

Teacher-16: Even if the children have strong numerical side or are interested in the problems, it is necessary to take care of those children one-by-one to gradually adapt them to the lesson. When I am teaching, I usually say to the children that whichever student is distracted or uninterested, I prefer to teach the lesson by asking good questions and talking together. (Transitional)

Teacher-22: In fact, I tell this to the children, "After I explain the topic, if you can apply it in another type of question or in another situation, it means that you have learned. If you can only solve the question that I explained in class, and if you can't solve that question at home, you haven't learned." Learning is holistic. (Transitional)

Teacher-8: Physics happens everywhere in life, and it is science that arouses people's curiosity in general. In other words, when you look at the universe, it is science that deals with everything from the smallest to the largest, and the first questions people ask are "why does it exist?" "how did the universe come to be, how did it develop?" and always looking for answers to these questions. Therefore, it is a science that attracts curiosity. Because it's always test-oriented, you know, its measurement, reliability or coverage is not much. Therefore, in that sense, we put ourselves in narrow patterns. We are trying to reveal our project-oriented side a little more with the children, sometimes in preparation for the Olympics, sometimes based on project development for competitions. (Constructivist)

Teacher-11: There is the subject of thermodynamics in physics, you know, which evaluates the behavior of multiple systems with macroscopic scales, or in fact, the behavior of society is a multiple system. It has a very complex system related to the economy, and people behave just like gases. (Constructivist)

Teacher-13: Physics encompasses them all, physics includes them all. For example, even during the first discovery of DNA, Francis Crick and James Watson came and asked physicists, "Is this how it balances?" So I know that physics is an all-encompassing thing. So I think that a person who knows physics will at least know the way it works, even if it's not a detailed body analysis, even if it's not a detailed body analysis in biology. So I think physics is fundamental, I think it's the foundation of everything. (Constructivist)

In these statements, teachers with traditional epistemological beliefs about simple knowledge thought that knowledge developed in a linear and organized process without any intervention. According to transitional teachers, knowledge came from everyday life and couldn't take information out of life, so teachers aimed to integrate technology and daily life problems as much as possible. For example, a teacher suggested that you experience inertia when you got on the bus, when the bus accelerated, you went backwards, or when it slowed down, you went forward. Some of these teachers stated that students' learning was influenced by their interest and prior knowledge, and the topics should be explained in detail to address the logic rather than memorization. These teachers tended to show simple experiments as demonstration and simulation to emphasize the theoretical aspects of the topics. Teachers with constructivist epistemology suggested that they had opportunities to conduct different kinds of experiments such as wave experiments, optics experiments, experiments with electricity; they emphasized that the design of models or experiments should enhance students' creativity rather than serving as a demonstration. Their approaches explained that physics learning should focus on logic, interpretation, and creativity instead of simplifying the physics into formula derivation to make measurements, construct hypothesis, and solve complex problems. These teachers suggested that physics could have a fundamental role in explaining the physical structure of the models in biology and chemistry or sociology and politics; these models or theories could be used to explain other models in other fields as well.

Table 3 summarized the experienced physics teachers' epistemological beliefs about certain, innate ability, source of, quick, and simple knowledge dimensions. The participants' overall epistemological profile at different dimensions was represented in Appendix 1. This profile was used to determine level of each teacher's epistemological belief profile through calculating the average value for traditional (1), transitional (2), and constructivist (3) levels at these dimensions. The final profile showed that most physics teachers (17, 57%) possessed transitional epistemological beliefs, whereas eight teachers (8, 27%) held constructivist views, and five teachers (5, 17%) had traditional epistemological beliefs. These results showed that transitional epistemological beliefs of the experienced physics teachers represented their approaches to focus on teaching through integrating natural observations and daily-life examples while emphasizing the theoretical information.

TABLE 4 Dimensions of physics teachers' practices.

		Traditional	Transitional
	Practice	N:23, 77%	N:7, 23%
a	Teacher-centered	84.57	75.00
a	Deskwork	95.87	78.57
a	Simulation/video/ demonstration	5.65	5.00
a	Smartboard/ white board	85.87	82.86
	Average	**57.37**	**51.80**
b	Prior conceptions	63.48	71.43
b	Real-life examples	10.00	28.57
b	Problem-solving	35.65	45.00
b	Models	66.52	80.00
	Average	**43.91**	**56.25**
c	Group work/ discussion	61.74	70.71
c	Student Presentation	1.74	21.43
c	Student-initiated questions	6.09	4.29
c	Questioning	43.04	68.57
c	Investigation	0.00	0.00
	Average	**22.52**	**33.00**

a, traditional; b, transitional; c, constructivist.

4.2 Physics teachers' teaching practices

Table 4 showed physics teachers' traditional, transitional, and constructivist practices in various proportions. Most teachers used a greater percentage of classroom time with traditional practices (N: 23, 77%) or transitional practices (N: 7, 23%); constructivist practices were not dominant although teachers usually utilized whole class discussion and questioning techniques. Traditional practices involved lecturing by using smartboard or whiteboard to make demonstrations while students were working passively on their desks. These traditional teachers' lecturing practices rarely involved the use of models and problem-solving by referring to prior conceptions. However, transitional teachers less likely utilized lecturing and deskwork than traditional teachers since they addressed prior knowledge, real-life examples, problem-solving, and modeling more. Although both traditional and transitional teachers integrated whole class discussions and questioning techniques to enhance student voice, inquiry-based experiments and student presentations were

TABLE 5 Relationship between beliefs and practices.

Belief Practice	Constructivist	Transitional	Traditional
Constructivist	0	1 (3.3%)	7 (23.3%)
Transitional	0	4 (13.3%)	13 (43.3%)
Traditional	0	2 (6.7%)	3 (10%)

missing in their constructivist classroom practices. These teachers involved simulations and demonstrations in small percentages of their 1 h classroom practices. These results showed that experienced physics teachers could enact transitional strategies with modeling, problem-solving, and discussion practices, but use of less constructivist practices were based on school-context and curriculum requirements.

4.3 The relationship between beliefs and practices of experienced physics teachers

The relationship between physics teachers' beliefs and practices was represented on Table 5. Most teachers' epistemological beliefs were at transitional level, whereas their classroom practices were aligned with traditional practices. Seven teachers held constructivist epistemological views to emphasize the value of tentative nature of knowledge that could be constructed through new evidence; however, they focused on lecturing with modeling and problem-solving on the board as transitional practices. Four teachers' epistemological beliefs and classroom practices were aligned at transitional level because these teachers focused on solving many problems through discussion and questioning to enhance student voice. Three teachers held traditional views for their epistemological beliefs and classroom practices since they valued lecturing through textbook information and used the smartboard to read the textbook. There were also misalignments: For example, only one teacher with constructivist epistemology enacted lessons at transitional level to integrate group work, real-life issues, student-questioning, and problem-solving. Other two teachers presented traditional epistemological beliefs even though their transitional practices focused on eliciting students' prior knowledge and enhancing their voice through referring to real-life issues. These results represented the negative and insignificant association between teachers' epistemological beliefs and classroom practices. Even though teachers held sophisticated epistemology, they tended to enact teacher-centered strategies to prepare students for standardized testing.

5 Discussion

Most experienced physics teachers in this study held constructivist beliefs that knowledge could change through new evidence from research. These teachers referred to role of project-based instruction in the knowledge construction. Some teachers held transitional beliefs that focused on diversity of ideas and abilities based on curiosity and interest. These teachers thought that learning depended on integrating theory into practice by using logic and effort, so they focused on the importance of mathematics, technology, and real-life applications in learning physics rather than addressing discovery processes. Most traditional-oriented teachers emphasized the role of sources such as textbooks, private tutors, and internet resources within the learning process. The results showed that participating teachers had sophisticated beliefs about certain knowledge since they believed that knowledge changes with new evidence and beliefs about innate ability to address both natural abilities and experience. These physics teachers tended to believe in the tentativeness of knowledge and the need for perseverance and logic to be successful. They suggested that students should be active participants of their learning process through scientific research and experience to develop responsibility as suggested by Suh et al. (2022). However, these teachers indicated limited beliefs about source of knowledge, quick and simple knowledge. Sengul et al. (2020) also found that science teachers tended to focus on the product rather than emphasizing the process of argumentation. Participating physics teachers in this study indicated that their role as teachers was providing clear directions to help students reproduce theoretical knowledge in a quick way. They focused on external authorities such as teachers, textbooks, or private tutors as the sources of knowledge generation. In summary, Turkish physics teachers had sophisticated beliefs about certain knowledge and innate ability, but they had limited views on source of, simple and quick knowledge. Bendixen and Corkhill (2011)'s study aligned with Turkish experienced teachers' sophisticated beliefs about certain and innate ability but misaligned with their limited views on simple knowledge. Turkish physics teachers' beliefs about certain knowledge were not aligned with another study: Napoleon-Fanis (2020) found that biology graduate teaching assistants' beliefs about certain knowledge were fixed and unchangeable and their beliefs about source of knowledge were depending on authority and research.

These experienced physics teachers' epistemological beliefs were mostly transitional, and a few teachers held constructivist views. In terms of practices, they preferred using teacher-centered strategies to lecture with smartboard or whiteboard while students were sitting passively on their desk. The lessons included largely traditional-oriented strategies rather than group work, peer teaching, and hands-on activities. These teachers also talked about their challenges in teaching through experimentation referring to their epistemology. Teachers with traditional beliefs stated that since physics laboratory did not include sufficient equipment for all students' experience of laboratory work, they tended to utilize online simulations and demonstrations for quick learning. Teachers with transitional epistemology organized their lessons around examples from real-life events, but classrooms were lacking the use of interactive communication to enhance students' explanations about physics. This result showed the divergence between teachers' epistemological beliefs and classroom practices. These teachers experienced the tension between teaching for learning and teaching for the test; this finding addressed the contradiction between epistemological beliefs and practices. These teachers presented the evidence that traditional-oriented practices were dominant in most schools in Turkey. The classroom culture was designed to facilitate teacher-centered instruction: students were passive at their desks, teachers were presenting the material on the board. These participating teachers' epistemological beliefs reflected that these teachers read, learned, and discussed about the significance of discovery processes in their teacher education programs and after becoming a teacher, but they did not have any opportunity to learn about how to enact reform-based strategies in their school context (Fives and Buehl, 2012; Bereczki and Karpati, 2018). These teachers needed to understand the benefits of enhancing learners' creative capacities using alternative pedagogies to enhance students' active participation and autonomy within the learning process. The school culture should support teaching and learning process to implement more innovative strategies to accommodate students' creative development.

Russ and Luna (2013) suggested that teachers could plan the classroom instruction to make students active participants within the process; they suggested the alignment between teachers' beliefs and classroom practices from a constructivist perspective. However, a few physics teachers had the alignment between epistemological beliefs and practices in this study. Four teacher held epistemological beliefs and classroom instruction at transitional level; they enhanced student voice through whole class discussion. Three teachers possessed epistemological beliefs and teaching at traditional level; they focused on transfer of knowledge in a didactic way to enhance their discipline and authority in the classroom. Other teachers presented the misalignment between their beliefs and practices that most teachers had traditional practices even though they held constructivist or transitional epistemological beliefs. These results showed that teachers might possess sophisticated beliefs, but classroom context and resources forced them to teach through teacher-centered strategies rather than integrating project-based instruction (Sengul et al., 2021). Experienced teachers were expected to enact student-centered strategies, assessment methods, and learning approaches.

There might be other factors influencing this inconsistency between teacher beliefs and practices such as teachers' perception of student learning, teaching science or inadequate equipment to conduct experiments. The misalignment of teacher-centered classroom practices of 13 teachers with their transitional epistemological beliefs or misalignment of teacher-centered classroom practices of seven teachers with their constructivist epistemological beliefs presented their teacher-centered or lecturing practices rather than student-oriented approaches. These teachers' practices indicated that teachers did not enact their constructivist or transitional epistemological beliefs since they tended to address students' expectations for quick and simple learning for the test preparation. These results aligned with the findings of Mansour (2013) and Rodgers et al. (2022) that teachers might modify their beliefs and practices to address students' expectations or students' learning progress. Some teachers held transitional beliefs and suggested the diversity among students, but they rarely addressed the equity issues to address needs of diverse students. Teachers might need to integrate alternative strategies to address multiple literacies in teaching and learning process.

In this study, participating experienced physics teachers taught different physics topics in their classrooms. Twenty-three of these teachers presented teacher-centered practices for students' learning expectations. The classroom contexts were similar with desks in rows in opposite to teacher's desk and whiteboard or smartboard. Physics lessons did not involve experimentation activities in any subject in these classrooms. However, Gunstone et al. (2009) and Caleon et al. (2018) found that experienced teachers tended to teach physics in traditional ways when the topic was complex and challenging; otherwise they tended to implement constructivist practices. For example, teachers in Gunstone et al. (2009)'s study focused on teaching DC electricity, they had difficulties with the concept and taught in traditional ways. These practices showed that experienced teachers might show conceptual inadequacies and epistemological uncertainties to integrate their sophisticated beliefs into practice. Teachers might also be influenced by their prior learning experiences as learners or expectations for standardized testing (Belo et al., 2014; Hansson et al., 2021). They needed guidance and professional development in being aware of and adapting reform-based strategies. Therefore, this study suggested that teachers should be supported to reveal their potential in enhancing student participation through discovery activities. Teacher education programs should support pre-service and in-service teacher development to promote learning by doing and experiencing rather than learning for the test. Ministry of National Education in many countries should help experienced teachers share their experiences and modify toward the use of student-centered instruction in various settings. Teachers should also learn how to conduct teacher research or action research or collaborative action research to examine their beliefs and practices while communicating with other teachers. Teacher reflective practices might serve as a guide to examine their beliefs and instructional experiences to suggest new methods to use in the classroom and enhance the level of their beliefs.

This study utilized qualitative dominant mixed method research with 30 experienced physics teachers. The sample size was relatively small size for a large-scale study even though the results presented the common patterns among participants. There was inconsistency between experienced physics teachers' epistemological beliefs and classroom practices that might be related to teachers' dysfunctional or irrational beliefs than their humanistic views (Samfira and Sava, 2021) since they prioritized the needs and expectations for exam preparation in teaching and referred to teacher perfectionism to decrease students' anxiety for testing (Samfira and Sava, 2023). Physics classrooms should promote sense-making and explanation to learn by doing and talking rather than direct transfer of information (Berland et al., 2016; Alzen et al., 2023). This study made suggestions for further research to examine the consistencies and inconsistencies between beliefs and practices focusing on teacher control ideologies (Ding and Wang, 2018; Samfira and Sava, 2023). Further research could be conducted through quantitative methods with several 100 physics teachers to establish the generalizability of findings and help teachers replace their dysfunctional beliefs with functional ones to enhance the relationship between epistemological beliefs and classroom practices. Additionally, this study focused on teachers' domain-general epistemological beliefs as core beliefs that were hard to change. The future research should also explore other belief dimensions such as beliefs about science in relation to classroom strategies. Besides classroom implementation, the alignment between teachers' epistemological beliefs and students' epistemological beliefs or the alignment between teachers' domain-general beliefs and their beliefs about teaching and learning should be investigated. The relation between epistemological beliefs, beliefs about science, and beliefs about teaching and learning should be examined to understand which one was more effective in teaching practices. In future studies, teachers should be supported to collaborate with other teachers to discuss the role of their beliefs in their practices and find out factors influencing this alignment or misalignment.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Boğaziçi Üniversitesi Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu (SBINAREK). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

OS: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1362426/full#supplementary-material

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