ASSESSING PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE OF HEAT AND TEMPERATURE THROUGH A VIGNETTE BASED INSTRUMENT

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DECLARATION OF ORIGINALITY

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ABSTRACT

Assessing Physics Teachers' Pedagogical Content Knowledge
of Heat and Temperature through a Vignette Based Instrument

This study aims to develop a vignette based instrument to probe in-service physics teachers' PCK of heat and temperature. The instrument focuses on two dimensions of PCK, namely (1) knowledge of student understanding and (2) knowledge of instructional strategies. The procedure of the instrument development consisted of conceptualizing PCK, developing preliminary items, conducting the first round of cognitive interviews, developing a comprehensive item pool, conducting the second round of cognitive interviews, administering the final instrument, and conducting descriptive statistics. The final form of the instrument consists of 24 items, with 12 items in the Knowledge of Student Understanding section and 12 items in the Knowledge of Instructional Strategies section. A total of 99 in-service physics teachers and 10 non-physics teachers participated in the study. To ensure the validity of the instrument, expert opinions were taken, cognitive interviews were conducted, and scores of physics and non-physics teachers were compared. Item analysis, item-total correlation, Cronbach's alpha correlation, and inter-rater correlation were conducted to evaluate the reliability of the instrument. The results of the study suggest that in-service physics teachers mostly made too general interpretations regarding student alternative conceptions. The physics teachers' interpretations of alternative conceptions of temperature were more sophisticated compared to heat and heat conduction. Similarly, most of the teachers' answers to items probing their knowledge of instructional strategies were false/irrelevant. Their performance on items eliciting knowledge of analogies and demonstrations was insufficient.

ÖZET

Fizik Öğretmenlerinin Isı ve Sıcaklıkla ilgili Pedagojik Alan Bilgilerinin Vinyet Tabanlı Bir Ölçekle Değerlendirilmesi

Bu çalışma, hizmet içi fizik öğretmenlerinin ısı ve sıcaklıkla ilgili pedagojik alan bilgilerini (PAB) incelemeyi hedeflemektedir. Bu amaçla vinyet tabanlı bir ölçek geliştirilmiştir. Ölçek, PAB'ın iki boyutuna odaklanmaktadır: (1) öğrenci anlayışı bilgisi ve (2) öğretim stratejileri bilgisi. Ölçek geliştirme aşamaları, PAB'ı kavramsallaştırma, ön maddeleri geliştirme, ilk bilişsel görüşmeleri yapma, kapsamlı bir madde havuzu geliştirme, ikinci bilişsel görüşmeleri yapma, son hali verilen ölçeği uygulama ve betimleyici analizleri yapmaktan oluşmaktadır. Ölçeğin son hali, Öğrenci Anlayışı Bilgisi bölümünde 12 madde ve Öğretim Stratejileri Bilgisi bölümünde 12 madde olmak üzere 24 maddeden oluşmaktadır. Çalışmaya toplam 99 hizmet içi fizik öğretmeni ve 10 fizik alanı dışından öğretmen katılmıştır. Ölçeğin geçerliliğini sağlamak için uzman görüşleri alma, bilişsel görüşmeler yapma ve fizik ve fizik alanı dışından öğretmenlerin puanlarını karşılaştırma gibi yöntemler izlenmiştir. Ölçeğin güvenilirliğini değerlendirmek için madde analizi, madde-toplam korelasyonu, Cronbach alfa korelasyonu ve değerlendiriciler arası korelasyon hesaplanmıştır. Çalışmanın sonuçları, hizmet içi fizik öğretmenlerinin çoğunlukla öğrencilerin kavram yanılgılarına ilişkin genel yorumlar yaptığını göstermektedir. Fizik öğretmenleri sıcaklıkla ilgili kavram yanılgılarına yönelik ısı ve ısı iletimine kıyasla daha detaylı yorumlar yapmıştır. Benzer şekilde, öğretmenlerin öğretim stratejilerine ilişkin bilgilerini ölçen maddelere verdikleri yanıtların çoğu yanlış ve ilgisiz bulunmuştur. Benzetme ve gösterimlere ilişkin pedagojik alan bilgisini inceleyen maddelere verdikleri yanıtlar da yetersiz bulunmuştur.

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ABBREVIATIONS

CoRe	Content Representations
MoNE	Ministry of National Education
PaP-eRs	Pedagogical and Professional Experience Repertoires
PCK	Pedagogical Content Knowledge
STEAM	Science, Technology, Engineering, Arts and Math
STEM	Science, Technology, Engineering and Math
VASI	Views about Scientific Inquiry
VNOS	Views of Nature of Science

CHAPTER 1

INTRODUCTION

Teaching cannot be characterized solely as information transmission but entails a complex consultation with various knowledge bases to enhance student learning (Wilson, Schulman & Richert, 1987). Since students may have diverse understandings, abilities, and interests, teachers must possess a special knowledge to meet these varying needs (Park & Chen, 2012). This knowledge should exceed content knowledge and pedagogical knowledge alone and enable teachers to transform content knowledge into an understandable form for students (NRC, 1996). Schulman (1987) defined this core knowledge type as pedagogical content knowledge within the broader framework of teacher professional knowledge.

Teachers' professional knowledge is multidimensional and consists of content knowledge, pedagogical knowledge, and pedagogical content knowledge. Schulman (1987) first described pedagogical content knowledge as a "blending of content and pedagogy" (p.9). He conceptualized the construct as an understanding of easy/difficult notions of a particular topic for students and how to sequence and organize ideas to meet students' diverse abilities. Following the emergence of this notion, researchers conceptualized pedagogical content knowledge as a type of "specialized professional knowledge" for teachers (Park, Suh & Seo, 2017, p.550).

There is consensus regarding several characteristics of PCK. First, all researchers agreed on the multidimensional nature of PCK. According to the models, PCK consists of different dimensions such as orientations to teaching, knowledge of student understanding, knowledge of instructional strategies, knowledge of curriculum, and knowledge of assessment. Among these dimensions, knowledge of

student understanding and knowledge of instructional strategies were the most used ones. Park and Chen (2012) mapped out the interrelations between different PCK dimensions and indicated that knowledge of student understanding and knowledge of instructional strategies were the most significant predictors of the coherence of the professional knowledge of the teachers. Another core characteristic of PCK that all models agreed on is its topic-specific nature (Baumert & Kunter, 2013). In other words, teachers might have different levels of PCK for different topics of a domain. In this regard, researchers investigated PCK for different topics of subjects such as organic chemistry, photosynthesis and electricity (Park, et al., 2018; Davidowitz & Potgieter; 2016; Bahçivan, 2012). Thus, investigating PCK for different topics of a subject is of importance. Finally, PCK is learnable and teachable (Bromme, 2001). Teachers can develop their PCK by gaining experience or engaging in professional development activities (Friedrichsen & Abell, 2013; Burton, 2013; Roth et al., 2011). Thus, efforts to examine and portray teachers' PCK is of particular importance.

Contemporary learning theories, such as situated cognition and conceptual change approach, stress the importance of student perspectives in education (Sawyer, 2014; Duit & Treagust, 2012). According to situated cognition, learning entails the construction of one's own knowledge in a socio-cultural environment (Wilson & Myers, 2000). In a similar vein, the conceptual change approach posits that learners incorporate new knowledge into their existing knowledge structures (Duit & Treagust, 2012). In this regard, eliciting students' understanding is important since one constructs knowledge by integrating it with his or her pre-knowledge. The models of PCK are well aligned with these contemporary learning theories since both perspectives stress the importance of the learning process on the student side. Specifically, PCK consists of knowledge of student understanding, including

preconceptions, alternative conceptions, and difficulties. Furthermore, knowledge of instructional strategies that elicit student understanding is also one of the most important components of PCK.

Student learning is influenced by a variety of student-related factors such as pre-knowledge and motivation as well as teacher-related factors such as PCK (Hegarty-Hazel, & Prosser, 1991; Förtsch et al., 2016). Results of numerous research studies suggest that teachers' PCK influences the planning of lessons, enactment of instruction, adoption of innovative teaching methods, and student outcomes (van Driel, Verloop & de Vos, 1998; Borko & Putnam, 1996; Roth et al., 2011). In a meta-review study regarding teachers' professional knowledge, PCK was found to be the strongest predictor of student performance (Coe, Aloisi, Higgins & Major, 2014). With this regard, the investigation of teachers' PCK has gained particular attention because the results of these investigations might contribute to efforts to enhance teacher learning through teacher training or professional development programs. Although there are a variety of studies that investigate teachers' pedagogical content knowledge for mathematics, such studies are comparatively rare for science and especially for physics (Chan, Rollnick & Gess-Newsome, 2019). Results of several of these studies suggest that teachers possess lower levels of PCK. For example, chemistry teachers could not infer students' difficulties and alternative conceptions of chemical bonding (Bergqwist, Drechsler & Rundgren, 2016). Teachers also have difficulty in supporting students to engage in inquiry activities (Abrahams & Reiss, 2012). Given the topic-specific nature of PCK, researchers suggest investigating PCK for specific topics rather than subjects. In this regard, this study aims to investigate in-service physics teachers' PCK of heat and temperature. Heat and temperature was chosen as the topic of the study because students face a variety of

difficulties in understanding the concepts of the topic and possess a variety of alternative conceptions (Osborne & Cosgrove, 1983; Harrison, Grayson & Treagust, 1999; Zacharia, Olympiou & Papaevripidou, 2008; Jasien & Oberem, 2002). Numerous studies were conducted to investigate students' preservice, and in-service teachers' understanding of heat and temperature (Jasien & Oberem, 2002; Paik, Cho & Go, 2007; Taqwa et al., 2019). However, there are very few studies that investigate teachers' PCK of heat and temperature and all of them were on pre-service teacher level. Thus, investigating in-service physics teachers' PCK of heat and temperature might give clues about the current instruction in high schools. Along with other factors, the low comprehension of heat and temperature concepts among students might be attributed to the pedagogical content knowledge levels of the teachers (Desimone, 2009), and investigating teachers' PCK might contribute to efforts that target enhanced student learning.

Chan and Hume (2019) identified five major research lines about PCK: (1) the nature of PCK, (2) the development of PCK, (3) the interrelations between PCK and other teacher-related constructs and student-related constructs, (4) the development of PCK after the implementation of an intervention, and (5) the development of measurement tools that aim to measure PCK. A variety of data sources were used in these investigations, such as observations, interviews, teacher artifacts, and written instruments. Although data sources such as observations depict deep illustrations of PCK, they may not be efficient to use on larger samples. In this study, interviews and a written instrument were used to probe in-service physics teachers' PCK.

In this study, the format of the instrument items was vignettes. Vignettes are defined as "contextualized descriptions of classroom instruction" (Brovelli et al.,

2014, p.555). They are also characterized as realistic scenarios of teaching and learning sequences (Kirschner et al., 2016). The vignettes depicted classroom scenarios about either knowledge of student understanding or knowledge of instructional strategies and probed in-service physics teachers to illustrate their PCK of heat and temperature.

1.1 Statement of the problem

Students possess a variety of alternative conceptions regarding heat and temperature concepts (Soeharto, Csapo, Sarimanah, Dewi & Sabri, 2019). For example, they could not differentiate heat from temperature, confuse heat with internal energy, or view heat as something possessable (Driver et al., 2014; Niaz, 2006; Başer & Geban, 2007). This may result from a variety of student or teacher-related factors. For example, it is well-established that teacher characteristics such as teacher knowledge and practice influence student outcomes (Förtsch et al., 2016; Mazibe, Gaigher & Coetzee, 2020). Thus, the way the topic of heat and temperature are taught in schools might contribute to students' difficulties and alternative conceptions (Hill, Loewenberg, Ball & Schilling, 2008).

Although there are a very high number of studies investigating students' understanding of heat and temperature, studies that investigate teachers' PCK of heat and temperature are scarce. The studies investigating PCK of heat and temperature were mostly conducted on pre-service level or teachers with small samples (Kartal, Öztürk & Ekici, 2012; Aydeniz & Gürçay, 2018; Yanti & Suhandi, 2020; Inaltekin & Akçay, 2021). This scarcity in literature results in a need for efforts to investigate in-service physics teachers' PCK of heat and temperature. In this regard, this study aims to develop a vignette-based instrument to probe in-service physics teachers' PCK of

heat and temperature. Definition of important terms within the scope of this study such as PCK, knowledge of student understanding and knowledge of instructional strategies are presented in APPENDIX A.

1.2 Research problem

This study aims to investigate one main research problem. The problem is related to developing a vignette-based instrument to probe in-service physics teachers' PCK of heat and temperature. Based on the research problem, the study's research questions are as follows:

i. What evidence was collected to ensure the validity and reliability of the instrument to probe in-service physics teachers' pedagogical content knowledge (PCK) of heat and temperature?
ii. What are the levels of in-service physics teachers' pedagogical content knowledge (PCK) of heat and temperature?

1.3 Significance of the study

This study aims to assess in-service physics teachers' PCK of heat and temperature. Since there was no instrument that assesses in-service physics teachers' PCK of heat and temperature, a new instrument was developed. The assessment framework of the instrument consists of the two most critical dimensions of pedagogical content knowledge: (1) knowledge of student understanding and (2) knowledge of instructional strategies and representations. Considering the topic-specific nature of pedagogical content knowledge, the study focuses on heat and temperature. The written instrument was developed as a paper and pencil test. The format of the items was vignettes. The items probed the physics teachers to express their knowledge of

student understanding and knowledge of instructional strategies. Various procedures, such as conducting cognitive interviews, comparing scores of in-service physics, pre-service physics, and non-physics teachers, and calculating the inter-rater reliability, were used to establish the validity and reliability of the instrument. Other researchers can use the instrument to probe in-service physics teachers' PCK of heat and temperature.

In today's world, teachers are expected to design effective learning environments in which students' conceptions and difficulties are addressed. In addition, teachers are expected to use effective instructional strategies that enhance student understanding. In other words, teachers are desired to possess higher levels of PCK. Friedrichsen et al. (2009) indicated that sources of teacher professional knowledge are their own experiences as students in K12 education, experiences throughout their profession, and teacher education programs and professional development activities. With this regard, the investigation of teachers' PCK has gained particular attention because the results of these investigations might contribute to efforts to enhance teacher learning through teacher training or professional development programs.

Teachers' pedagogical content knowledge influences their classroom planning, enactment, and student outcomes. Thus, the development process of PCK, its interrelations with teacher characteristics, and its influence on student learning processes should be rigorously examined (Großschedl et al., 2019). With this regard, researchers call for studies that examine teachers' PCK levels on different topics of different subjects. However, research studies that investigate teachers' pedagogical content knowledge in physics are rare, especially compared to mathematics. Given the topic-specific nature of pedagogical content knowledge, this study contributes to

the literature by assessing physics teachers' PCK of heat and temperature. To our knowledge, no instrument assesses physics teachers' PCK of heat and temperature on the in-service teacher level. Since heat and temperature entail a variety of teaching and learning difficulties, the results of this study might inform efforts to support preservice and in-service teachers. Specifically, students have a variety of alternative conceptions and experience difficulty in comprehending the abstract concepts of heat and temperature. The correct conceptualization of heat and temperature concepts is also necessary for the future endeavors of students in universities (Yeo, Lim, Tan & Ong, 2020). Along with other factors, teachers' PCK is a significant predictor of student success. Thus, examining physics teachers' PCK of heat and temperature has a potential to enhance teacher practice as well as student outcomes. Furthermore, since the development process of the paper and pencil instrument is elaborately explained, the findings of this study might inform other researchers who aim to conduct similar studies for other topics of physics.

CHAPTER 2

LITERATURE REVIEW

Teachers' pedagogical content knowledge is critical in their planning of lessons, adoption of new instructional strategies and student learning. Thus, the investigation of PCK receives particular attention within the educational field. In this chapter, a literature review of conceptualization, core characteristics and models of PCK is presented. Moreover, literature on how PCK is investigated in the educational field was also reviewed. Specifically, literature about the investigation of the nature of PCK, development of PCK, interrelations between PCK and other constructs, and test development studies are reviewed. Then, data sources used in PCK investigations are also elaborated. Since this study aims to develop a written instrument that aims to probe physics teachers' PCK of heat and temperature, a systematic review of research studies that use written instruments is made.

2.1 Conceptualization and core characteristics of teacher knowledge and PCK

Conceptualization of teacher professional knowledge is regarded as critical since these efforts enable researchers to identify characteristics of high-quality teaching and determine ways to enhance student learning (Goreth, Geisel & Rehm, 2015). Schulman (1986) provided the initial foundations of research on teacher knowledge and distinguished between three types of teacher knowledge: (1) subject matter content knowledge, (2) pedagogical content knowledge (PCK) and (3) curricular knowledge (p.9). According to him, pedagogical content knowledge entails procedures to represent content matter in a way that makes it comprehensible to others (p.9). He defined PCK in terms of "the missing paradigm" and challenges the

assumption that explains teaching success by only content expertise or pedagogical knowledge. In 1987, Schulman reformulated the dimensions of teacher professional knowledge as (1) subject matter content knowledge, (2) pedagogical knowledge, and (3) pedagogical content knowledge. Subject matter content knowledge is defined as facts and concepts of a specific domain that teachers should possess to enact successful instruction and guide students' learning process. Pedagogical knowledge (PK) is defined as general principles of organizing and managing classroom and classified as subject independent. Pedagogical content knowledge (PCK) refers to the transformation of subject matter in a way that makes it comprehensible for students. Bromme (2001) classified these dimensions as the topology (content) of professional knowledge. Furthermore, it was also indicated that teacher professional knowledge can be differentiated in terms of type/areas (Kirchner et al., 2016; Bromme, 2001). Types of professional teacher knowledge are declarative, procedural and conditional knowledge. Declarative knowledge is defined in terms of facts, principles and rules whereas procedural knowledge is defined as how to proceed in certain circumstances. Conditional knowledge, on the other hand, entails the logic behind rules and processes as well as informed decisions of teaching sequences. Thus, topology together with type constitutes the main and complex features of professional knowledge (Großschedl et al., 2019).

Although there are a variety of definitions of pedagogical content knowledge, researchers have used several common facets to conceptualize the term. The most widely accepted facets of pedagogical content knowledge are knowledge of students' understanding and knowledge of instructional strategies (Hill, Ball & Schilling 2008; Park & Oliver, 2008). Knowledge of student understanding is defined as teachers' knowledge of concepts that are hard for students to learn and that students perceive

as difficult, the prerequisite knowledge for learning a particular topic, and an awareness of differences in students' approaches to learning (Magnusson et al., 1999; Gess-Newsome, 2015). Knowledge of instructional strategies are defined as teachers' knowledge of particular strategies and methods such as activities, demonstrations and representations to help students understand a specific science topic (Magnusson et al., 1999).However other facets such as knowledge of curriculum and assessment are regarded within the conceptualization of pedagogical content knowledge by other researchers (Tamir, 1988; Magnusson, Krajcik and Borko., 2002).

Researchers also achieved a consensus regarding several core characteristics of pedagogical content knowledge. One of these features is the "learnable and teachable nature" of pedagogical content knowledge. The differences found between preservice teachers and in-service teachers imply that teachers develop a repertoire of pedagogical content knowledge as they engage in teaching practices (Bromme, 1992). Großschedl et al. (2019) indicated that this notion is highly relevant for the design of teacher education programs. These researchers also indicated that detecting differences in PCK scores between in-service and preservice teachers implies validity for the instrument that is used.

Another core characteristic of pedagogical content knowledge is its domain-specific nature (Baumert & Kunter, 2013). Since pedagogical content knowledge entails a transformation of subject matter for pupils' understanding, it is domain-specific. With this regard, researchers measured teachers' pedagogical content knowledge on different domains such as mathematics and physics as well as on different topics such as organic chemistry and photosynthesis (Großschedl et al., 2019; Park, et al., 2018; Davidowitz & Potgieter; 2016). By taking into account the domain-specific characteristic of pedagogical content knowledge, a written

instrument was developed to assess teachers' pedagogical content knowledge of physics.

2.2 Models of PCK

Since the foundation of research of pedagogical content knowledge by Schulman, a variety of models have been proposed such as the integrative vs transformative model, Pentagon model and consensus model. This variation in the conceptualization and models of the construct has led a complexity in the PCK research area. With this regard, a conference which is called PCK summit is held with the participation of international scholars to analyze the commonalities and divergencies in the conceptualization of pedagogical content knowledge (Park et al., 2018). This conference was sponsored by the National Science Foundation (NSF) and resulted in a consensus model of pedagogical content knowledge (Gess-Newsome, 2015). In this section, several previous models as well as the consensus model of pedagogical content knowledge is presented.

Gess-Newsome (2002) distinguished between two different models of pedagogical content knowledge: integrative model and transformative model (See Figure 1). According to the researcher, these models have different assumptions regarding the dimensions of pedagogical content knowledge. The integrative model assumes that pedagogical content knowledge is not a distinct dimension but rather an integrated component. According to this model, pedagogical content knowledge is constituted by the intersection of subject matter knowledge, pedagogical knowledge and contextual knowledge. On the other hand, the transformative model proposes that pedagogical content knowledge is a distinct dimension of teacher professional knowledge. Thus, pedagogical content knowledge is the resulting knowledge

dimension of an active manipulation and transformation process of subject matter knowledge, pedagogical knowledge and contextual knowledge.

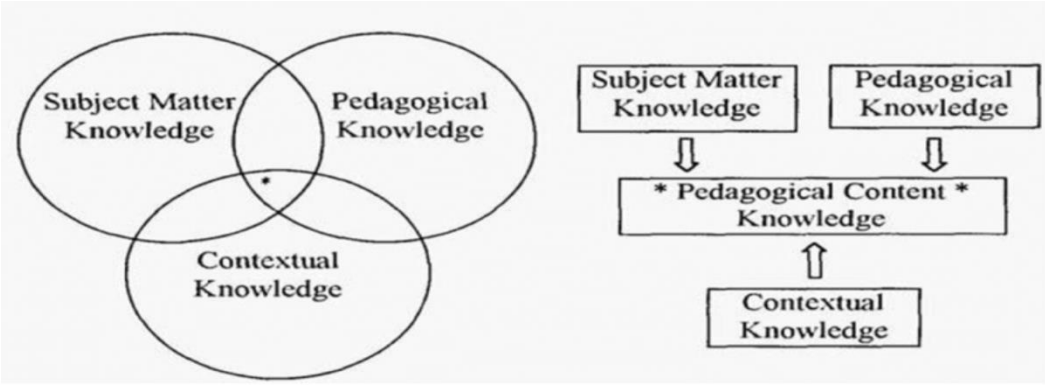

Figure 1. Integrative and transformative model of PCK
Source: Gess-Newsome, 2002, p.12

Another widely used model of pedagogical content knowledge is the pentagon model. This model is informed by the work of Grossman (1990), Tamir (1988) and Magnusson et al. (1999). According to this model, pedagogical content knowledge is a distinct dimension but is reciprocally influenced by other knowledge domains such as subject matter, pedagogy and context (Tamir, 1988). This model also indicates that pedagogical content knowledge consists of orientations towards science teaching which influences knowledge of science curriculum, knowledge of assessment, knowledge of students' understanding and knowledge of instructional strategies. The components and sub-components of pedagogical content knowledge is presented in Figure 2.

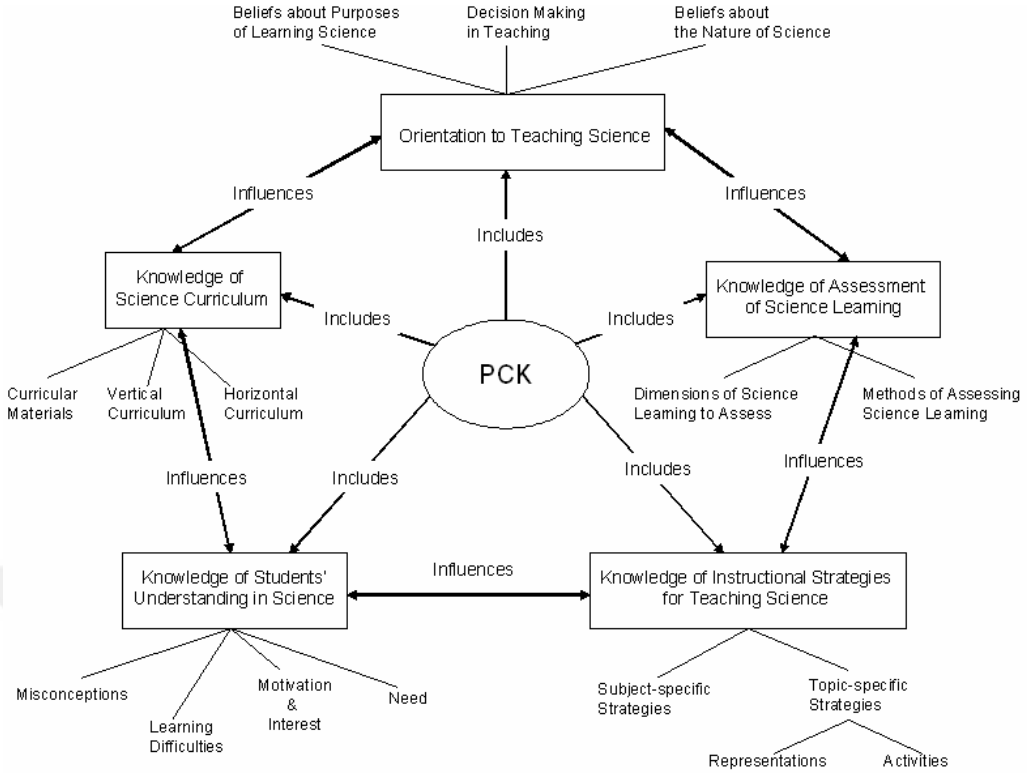

Figure 2. Pentagon model of PCK
Source: Magnusson et al., 1999, p.99

The consensus model emerged from the PCK summit that is held to synthesize the similar and diverse approaches to pedagogical content knowledge (Park et al., 2018; Gess-Newsome, 2015). One distinct feature of this model is the inclusion of practice within the professional knowledge framework (Gess-Newsome, 2015). This model also explicitly recognizes professional knowledge as topic-specific (See Figure 3). Topic-specific professional knowledge is defined in terms of students' understanding, instructional strategies and science practices. According to the model, topic-specific professional knowledge is informed by distinct knowledge bases such as assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students, and curricular knowledge. Furthermore, the model implies recursive interrelations between topic-specific professional knowledge, classroom practice, and

student outcomes. These different constructs are linked to each other through several amplifiers and filters. For example, how topic-specific professional knowledge is enacted in the classroom is influenced by teachers' beliefs and context whereas how teacher practice leads to student outcomes is influenced by students' beliefs and prior knowledge. Thus, this model provides a more comprehensive framework to explain the reciprocal interrelations between teacher knowledge, classroom practice, and student outcomes (Gess-Newsome, 2015).

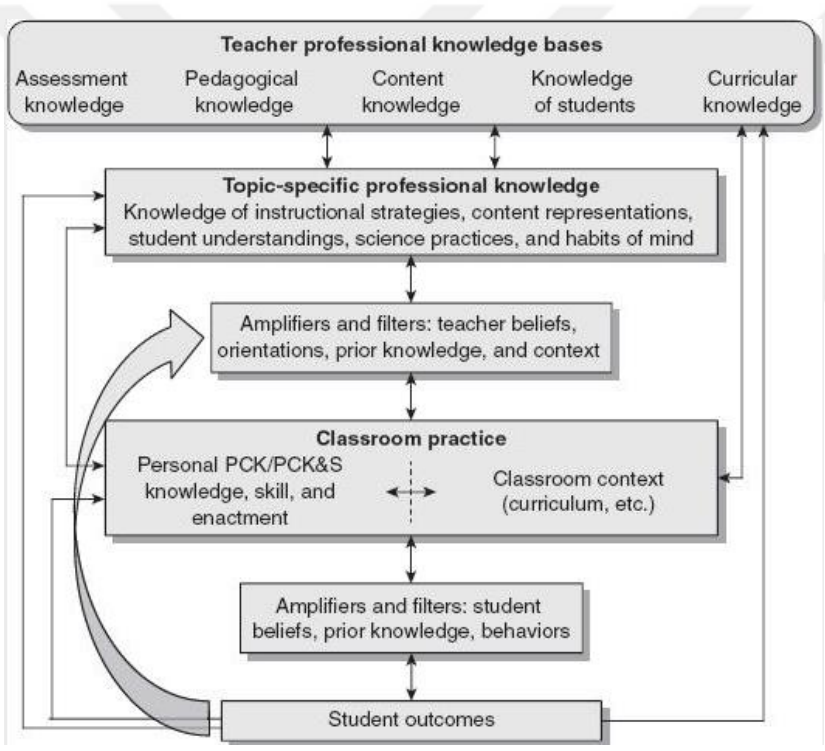

Figure 3. Consensus model of PCK
Source: Gess-Newsome, 2015, p.31

After the first summit, PCK researchers conducted a second summit and developed the Refined Consensus model of PCK (See Figure 4). The focus of the second summit was more on the contributions of science teacher education research on teacher education or professional development programs rather than achieving a

consensus (Carlsen et al., 2019). Thus, a broader model of PCK was conceptualized to entail different types of PCK and to appeal to more lines of PCK research studies. According to this model, teachers enact their knowledge as they continuously plan, teach, and reflect. The enactment of PCK (ePCK) is influenced by personal PCK (pPCK) which is shaped by teachers' continuous experience with students, curriculums, and learning environments. In this regard, the learning context is defined in terms of student characteristics and the context in which teaching occurs. The collective PCK (cPCK) surrounds the learning context and implies the PCK which is shared by teachers. Finally, different forms of PCK are informed by different knowledge bases such as pedagogical knowledge, knowledge of students, and knowledge of assessment (Carlsen et al., 2019).

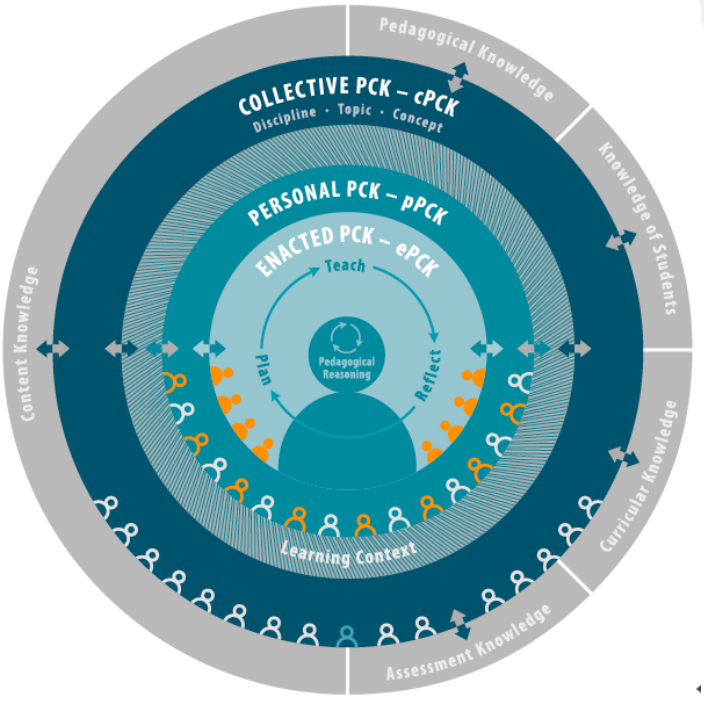

Figure 4. The Refined Consensus Model of PCK
Source: Carlson & Daehler, 2017, p.83

In this study, the Refined Consensus model of PCK was used as the theoretical framework of the instrument. This model was used because it is the most recent model that a variety of PCK researchers collaboratively developed. Furthermore, the model depicts a more comprehensive framework to appeal to a variety of research studies (Carlsen et al., 2019). For example, different forms of PCK such as enacted, personal and collective were considered within the framework of the model.

2.3 Investigation of PCK in science education research

Since the establishment of the pedagogical content knowledge research area, a significant amount of research has been conducted. Chan and Hume (2019) identified five major areas of research in science education which focus on (1) the nature of PCK, (2) the development of PCK in teacher programs or teaching settings, (3) the interrelations between PCK and other teacher-related constructs such as motivation, attitudes, and cognition as well as student-related constructs such as performance, (4) the development of PCK after the implementation of an intervention, and (5) the development of measurement tools that aim to measure PCK. Below, examples of literature of each research area are presented.

2.3.1 Investigation of the nature of PCK

Research investigating the nature of PCK generally focuses on the exploration of the construct as well as the interrelations between the PCK components. For example, Großschedl et al. (2015) investigated preservice biology teachers' professional knowledge by specifically analyzing their pedagogical knowledge, content knowledge and pedagogical content knowledge. The researchers obtained empirical evidence regarding the distinction of PCK from other knowledge types.

In this line of research, characteristics, and sources of teachers' PCK and PCK dimensions were also investigated. In a study of teachers' conceptions about student understanding of acids and bases, Lin and Chiu (2010) found that chemistry teachers could correctly anticipate only high achieving students' conceptions. Teachers' ideas about the sources of low-achieving students' understanding were inaccurate and they tend to attribute student failure to intuition rather than their way of teaching. In another study, Kellner et al. (2011) investigated preservice science teachers' conceptions of student difficulties in four subjects and concluded that these conceptions should serve as a starting point for professional development programs. Alonzo and Kim (2015) conducted another study about the nature of PCK by focusing on different forms of PCK of physics teachers. They used video-based interviews as data sources and found that teachers use their declarative PCK as a source for their dynamic PCK of force and motion. Aydın and Boz (2013) conducted a study with chemistry teachers and indicated that knowledge of student understanding and knowledge of instructional strategies were much more central in the integration of PCK components compared to knowledge of assessment and knowledge of curriculum. In other words, teachers consult more on their knowledge of student understanding and knowledge of instructional strategies while teaching compared to other dimensions of PCK.

Loughran, Mulhall and Berry (2004) conducted a study to capture high school science teachers' pedagogical content knowledge. The researchers used CoRe (Content Representations) and PaP-eRs (Pedagogical and Professional Experience Repertoires) as research tools to explore and portray teachers' pedagogical content knowledge. These tools enable researchers to make interviews, focus group discussions and observations within a framework. Specifically, CoRe's target

teachers' understanding of the core concepts of the unit, students' prior and alternative conceptions, effective sequencing of the ideas and use of instructional strategies. PaP-eRs provide detailed accounts of teachers' experiences elicited by interviews as well as classroom observations. These tools provide teachers with questions that stimulate them to reflect on their pedagogical content knowledge.

Along this line of research, the nature of PCK of novice and experienced teachers were also investigated and compared (Chan & Hume, 2019). For example, Krepf et al. (2017) asked novice and experienced physics teachers to analyze a video of teaching and examined which CK and PCK constructs they activated. The results of their study suggested that experienced teachers consult much more on their CK and PCK while analyzing lessons. Specifically, they made significantly more relevant comments about concepts, misconceptions, instructional strategies, and the structure of lessons. In a similar vein, Akın and Uzuntiryaki-Kondakçı (2017) investigated the interplay between different components of PCK for novice and experienced chemistry teachers. The researchers found that experienced teachers were much more successful than the novice teachers to integrate the PCK components and translate their knowledge into practice.

Several researchers explored teachers' PCK of specific topics. For example, Melo-Nino, Canada and Mellado (2017) investigated physics teachers' PCK for each dimension as well as orientations to science teaching for the physics topic electric field. The researchers indicated that physics teachers adopt more teacher-oriented instruction due to the high abstract level of the topic, limited time available to teach the content, and the pressure of high-stakes exams. The physics teachers in their study could not elicit sufficient student difficulties and misconceptions, and used teacher or content centered instructional strategies. Similarly, Mthethwa-Kunene,

Onwu and de Villiers examined in-service biology teachers' content knowledge, knowledge of student understanding and knowledge of instructional strategies for teaching genetics. The researchers indicated that although biology teachers use instructional strategies such as demonstrations and analogies, they could not effectively use models and experiments in their classrooms. Moreover, their knowledge regarding student understanding of genetics was limited.

Aydın and Boz (2013) investigated the topic-specific nature of PCK. The researchers conducted a qualitative study with two experienced chemistry teachers as they were teaching two different topics. The researchers concluded that two dimensions of PCK namely as knowledge of student understanding and knowledge of instructional strategies were topic-specific whereas the remaining two dimensions of PCK were not topic-specific. However, they also cautioned the generalizability of the results due to the low sample size. Kind (2017) proposed an evidence-based rubric that classifies correct, incorrect, relevant, and complete descriptions of science teachers' topic-specific professional knowledge for teaching different topics.

In another study, Bergqwist, Drechsler and Rundgren (2016) investigated chemistry teachers' knowledge of teaching models. The researchers indicated that chemistry teachers lack sufficient knowledge of student difficulties and use representations without eliciting any student understanding. Furthermore, they do not fully comprehend how the use of models could flourish or impede student understanding. In a related study, Bergqwist and Rundgren (2017) found out that teachers' choice of models is primarily determined by whether the models are included in the textbooks or not. The researchers cautioned that teachers use models in textbooks even when the models are insufficiently presented and may cause

student difficulties. Thus, they portrayed textbooks as very influential on teacher knowledge and instruction.

Friedrichsen, van Driel and Abell (2010) stated that there is an ambiguity about the definition of the orientations toward science teaching which is a central element of the Magnusson's model of PCK. To solve this ambiguity and clarify its interrelations with other PCK constructs, the researchers proposed a new definition of the construct. According to the researchers, orientations to science teaching should be defined in terms of beliefs, views of science and goals and purposes of science teaching. In their study, Park and Chen (2012) also provided empirical evidence regarding the central role of orientations in science teaching on the integration between PCK components. The researchers concluded that teachers who adopt a didactic orientation tend to prevent their knowledge of instructional strategies from interrelating with other PCK components. In other words, the instructional strategies they use in classrooms are insufficiently informed by their knowledge of student understanding, curriculum, and assessment. To empirically investigate orientations to science teaching, Demirdöğen (2016) examined how preservice science teachers' orientations toward science teaching influence other components of PCK. The researcher found that preservice teachers with more reform-based beliefs about science teaching tend to use more student-centered instructional strategies. In a similar vein, Boesdorfer and Lorsbach (2014) investigated the interrelations between the orientations toward science teaching and the practice of teaching. The researchers found that beliefs regarding the importance of student-centered learning reflect themselves in teacher practice. Specifically, teachers who believe that students should take the responsibility of their own learning use more student-centered approaches such as guided inquiry and performance assessment. In a different study,

however, Qhebala and Moru (2013) obtained different findings. The researchers indicated that physics teachers who believe in the importance of student-centered teaching still tend to use didactic approaches during their instruction. The contradiction observed in this finding was explained by teachers' statements about insufficient equipment and students' negative attitudes to inquiry learning which requires much more effort.

Along the research line of PCK nature, levels of PCK were also investigated. Schiering et al. (2023) proposed a model that describes different levels of PCK of preservice physics teachers. In other words, a model that characterizes the attributions of high, average, and low levels of PCK was explained. Preservice teachers with high levels of PCK were found to elicit students' alternative conceptions and use instructional strategies specific to the content. However, lower levels of PCK were associated with little reference to student understanding while choosing instructional strategies. In another study, Chen and Wei (2015) examined chemistry teachers' adaptation of reform-based curriculum materials in China. The researchers found that knowledge of student understanding and knowledge of assessment were the most predictive PCK dimensions of curriculum adaptation.

2.3.2 Investigation of the development of PCK

Another research area that is popular among PCK research is the development of PCK. Besides from the nature of PCK, researchers also aimed to understand how PCK is developed in teacher programs or in natural teaching settings within a time frame. In this regard, Sorge et al. (2017) investigated the interrelationship between content knowledge, pedagogical knowledge, and pedagogical content knowledge of preservice physics teachers at the beginning and end of two years of teaching. The

researchers indicated that at the beginning of their teaching, preservice teachers relied more on their pedagogical knowledge whereas at the end of a two-year teaching they relied more on their content knowledge. Thus, developed PCK is associated with content specificity.

Vergara et al. (2024) proposed that teachers' development of PCK cannot be separated from a collective form of PCK. Thus, the researchers aimed to describe the development of personal PCK within the development of collective PCK of a group of biology teachers as they participate in a professional development program. As the biology teachers share their teaching experiences, they have discussions about conceptions of students, instructional strategies, and assessment techniques they use in classes. This collective PCK results in the enhancement of teachers' personal PCK.

Development of PCK in microteaching settings was also investigated by several researchers. Brown, Friedrichsen, and Abell (2013) investigated the PCK development of preservice biology teachers over a course year. A student-centered learning approach is introduced and elaborated to preservice teachers in their methods course. The preservice teachers are introduced to 5E learning and required to design a curriculum that reflects the tenets of this approach. Meanwhile, the preservice teachers were observed and interviewed as they were microteaching in schools. The researchers indicated that although the preservice teachers learn a student-centered approach in their methods course, they were reluctant to apply it in their classes. Moreover, their orientations to teaching science were more teacher directed and resistant to change over their teaching experiences. Although the preservice teachers increased their awareness of student understanding and started to use different instructional strategies during their teaching, their orientations to

science teaching did not significantly change. The researchers pointed out the importance of designing methods courses that elicit preservice teachers' conceptions of science teaching.

In another study, Bayram-Jacobs (2019) investigated the development of science teachers' PCK as they enact novel curriculum materials. Specifically, science teachers from four different countries applied new curriculum materials which has an emphasis on socioscientific issues. The curriculum materials aimed to enhance science teachers' PCK of teaching socioscientific issues and at the same time equip students with knowledge and skills that guide them to make informed decisions in a rapidly developing world. Students are desired to become proficient in making arguments and evaluating arguments in terms of evidence. The results of their study suggest that science teachers enhanced their knowledge of student understanding and knowledge of instructional strategies as they enact novel curriculum materials.

In a different study, Findlay and Bryce (2012) found that as preservice teachers gain experience, they enhance their repertoires of student understanding and try to make the content comprehensible for students rather than just transferring it. Sickel and Friedrichsen (2017) also indicated that at the beginning of their careers, teachers are more goals oriented and choose instructional strategies that fit with the curriculum goals. As they gain experience, teachers tend to place heavier emphasis on making the topic understandable for students rather than merely adhering the goals. Luft et al. (2022) also investigated the longitudinal development of science teachers' beliefs, PCK and practice. The researchers indicated that although teachers' beliefs did not significantly change over a five-year period of time, their PCK and practice improved.

In a different vein, Chan and Yung (2015) proposed a three-step model about how PCK is developed during moment-to-moment teaching. The stimulus-integration-response model asserts that unpredicted student questions and responses enhances the development of pedagogical content knowledge and results in development of novel instructional strategies by the teachers.

Along this line of research, the development of PCK in the presence of a mentor was also investigated. Barnett and Friedrichsen (2015) examined the development of PCK of a preservice biology teacher as he was microteaching biology in a high school. The researchers examined how his PCK is developed as he worked with a mentor. The results of their study suggest that discussions with a mentor about the differences between didactic and inquiry approaches contributed to the PCK of the preservice teacher. Furthermore, in depth inquiries to the nature of student learning, reflecting on different types of instructional strategies and talking about alternative conceptions emerged from the classroom discussions also facilitated the PCK growth of the preservice teacher. In a similar study, Can-Küçük, Gencer and Akkuş (2022) also investigated preservice chemistry teachers' development of PCK throughout a mentoring process. The results of their study suggest that preservice teachers' PCK developed after the mentoring. However, the degree of development was not same for each student. Specifically, students with higher academic achievement benefited most from the mentoring in terms of PCK development.

2.3.3 Investigation of the interrelations between PCK and other constructs

Another PCK research area delves into the interrelations between PCK and teacher- and/or student-related constructs. Investigations about the interrelations between

subject matter knowledge and PCK constitute a large portion of this research area. For example, Kaya (2009) examined the interrelations between preservice science teachers' pedagogical content knowledge and content knowledge. The researcher applied a test that measures content knowledge and then assigned each preservice teacher to high, average, and low ability groups. By conducting interviews, the researcher concluded that high ability preservice teacher groups possessed higher PCK compared to other groups. In a similar vein, Davidowitz and Potgieter (2016) indicated that subject matter knowledge is essential but not sufficient for a high level of PCK. Rollnick (2017) found that physical science teachers developed their content knowledge as well as pedagogical content knowledge in harmony as they are teaching a topic that they did not know before. In other words, as the teachers gain teaching experience, their content knowledge also increased. Lucero, Petrosino and Delgado (2016) observed no interrelation between subject matter knowledge and knowledge of student understanding. However, the researchers indicated that a specific amount of subject matter knowledge is needed for teachers to elicit students' alternative conceptions.

Şen, Demirdöğen and Öztekin (2022) also investigated the interrelations between content knowledge and PCK in a slightly different manner. The researchers specifically focused on the influence of content knowledge on the interrelations between PCK dimensions. In their study, teachers were classified according to their content knowledge. Then, data regarding the interrelations between PCK dimensions were analyzed through interviews and classroom observations. The results of their study suggest that teachers with least content knowledge have the least integrated PCK dimensions.

Stender, Brückmann and Neumann (2017) investigated the influence of PCK on teaching practice as well as the moderating effects of motivation and self-regulation on this relationship. The researchers concluded that when the teachers have higher motivation and self-regulation, the relationship between PCK and the quality of teaching practice was stronger. Similarly, Park et al. (2011) found that teachers with higher PCK tend to imply more reform-oriented instruction. The sustainability of the implementation of innovative teaching methods was investigated by Suh and Park (2017). The researchers indicated that teachers with student-centered teaching orientations tend to have higher knowledge of student understanding and instructional strategies. In addition, the high PCK enables teachers to sustain their implementations of innovative teaching methods. The researchers also concluded that the relations between PCK and sustainable implementation was mutual and interactive.

Interrelationships between PCK and other teacher characteristics such as self-concept and self-regulation were also investigated. Paulick et al. (2016) indicated that physics and chemistry teachers with positive self-concept had higher professional knowledge including PCK. In a similar vein, Yeung, Craven and Kaur (2014) found that teachers with positive self-concept tend to adopt student-centered approaches during their teaching practice. Uzuntiryaki-Kondakçı et al. (2017) investigated the interrelations between teacher self-regulation and PCK. The researchers found that teachers with higher PCK tend to regulate their teaching more effectively.

Several researchers investigated the influence of PCK on student-related variables. Förtsch et al. (2016) indicated that teachers' PCK influences student learning via the mediation of the activation of cognition. In other words, teachers

with higher PCK tend to elicit cognitive activation of their students which results in enhanced learning. While implementing a project-based science program, teachers' content knowledge and PCK tend to correlate with student performance (Kanter & Konstantopoulos, 2010). In another study, Mahler, Großschedl and Harms (2017) investigated the influence of content knowledge and PCK on system thinking performance of students. The researchers found that not content knowledge, but PCK is positively correlated with student performance. The researchers attributed an indirect effect to content knowledge through PCK and called for further investigations.

In another study, Mazibe, Gaigher and Coetzee (2020) investigated the interrelations between teacher practice and student learning of electrostatics. The researchers used interviews and observations as data sources. Based on rubrics that classify distinct levels of PCK, the researchers coded data obtained from the interviews and observations. The results of their study suggest that students' performance was moderately and significantly related to teachers' PCK.

Yang, Liu and Gardella Jr. (2020) investigated the interrelations between teacher practice and student outcomes by proposing mediational relationships. The researchers situated their study in the context of a professional development program and examined the program's influence on teacher as well as student factors. The results of their study suggest that the professional development program enhanced science teachers' implementation of inquiry in their classrooms. While explaining the increase in students' performance, the researchers draw a mechanism: Teacher enactment of inquiry leads students to experience inquiry which enhances their self-efficacy beliefs. The increase in self-efficacy beliefs finally leads to increased performance.

2.3.4 Investigation of the development of PCK after an intervention

The fourth research area of PCK focuses on the influence of interventions on PCK of the teachers. The form of the interventions was generally a methods course for preservice teachers and a professional development program for in-service teachers. For example, Aydın et al. (2015) investigated the influence of a methods course on preservice chemistry teachers' PCK. The researchers revised a classical methods course which they called "CoRe based mentoring-enriched practicum". During the course, preservice teachers are introduced to the concept of PCK as well as the content representations (CoRe's) as an alternative means to prepare lesson plans. Furthermore, preservice teachers are periodically assisted by mentors as they plan, enact, and reflect on the lessons. The mentors guided the preservice teachers to make an inquiry into their own teaching rather than telling them what to do. CoRe's are introduced as a tool that requires teachers to think about what to teach, why to teach, why the topic is important, what misconceptions/difficulties students have and how the topic could be made comprehensible for students and so forth. CoRe's also served as a data analysis tool for the researchers that reflect the progression of the preservice teachers' PCK. The results of their study suggest that the educative mentoring and use of CoRe's enhanced preservice chemistry teachers' PCK.

In another study, Mansfield (2023) designed an intervention to enhance preservice physics teachers' PCK to plan practical work. The practical work referred to the laboratory in their study. The intervention was in a form of a methods course and consisted of several steps. Throughout the course, students first make interpretations regarding the ill structure of practical work. Then, they recalled and reflected on their own laboratory experiences. This step is followed by engaging in practical work. As preservice teachers engage in practical work, they reflected on the

necessary cognitive and practical skills required to do experiments. Then, they do micro teaching and make reflectionsont their own teaching. The intervention was effective in terms of enhancing preservice teachers' knowledge of planning practical work.

Hoppe et al. (2024) targeted the development of a single dimension of PCK as they implement a professional development program for preservice science teachers. The professional development program was, in their own words, practice based and aimed to improve preservice science teachers' knowledge of assessment. Preservice teachers attended lessons about PCK and assessment during the professional development program. Furthermore, they watched segments of videos of classroom interactions. As they watch the videos, they assess the student statements in collaboration with their peers. Then they had the opportunity to compare their assessments with experts' assessments. The results of the study suggested that a practice based professional development program significantly enhanced preservice teachers' knowledge of assessment.

Scharfenberg and Bogner (2016) designed an intervention to improve preservice biology teachers' PCK. The researchers applied a new method which they called role change. During the intervention, the preservice teachers attended three different sections of the program in which they assumed the role of a student, tutor, and teacher respectively. They brainstormed, engaged in group and whole class discussions, and conducted experiments. The results of the study suggest that explicitly assuming different roles contributed to preservice teachers' PCK. Specifically, preservice teachers' teaching orientations became more-student centered. In addition, preservice teachers advanced their repertoire in terms of eliciting student conceptions as well as choosing instructional strategies that address

these conceptions. In another study, Donnelly and Hume (2014) aimed to investigate the effects of a technological tool that fosters collaboration among preservice teachers as they prepare their CoRe's. The researchers created a technological environment which enables preservice teachers to review each other's CoRe's and share sources with each other. The results of their study suggest that reviewing each other's CoRe's gave preservice teachers an opportunity to critique their own CoRe's and their repertoire of student understanding.

Several studies investigated the effects of interventions for in-service teachers. Buma, Simanda and Rollnick (2023) investigated the influence of a professional development program on science teachers PCK. The intervention focused on topic specific pedagogical content knowledge of the particulate nature of matter. The results of the study suggest that science teachers' use of representations in classrooms increased and diversified. In a different study, Bravo and Cofre (2016) examined the influence of a learning study on biology teachers' PCK. During the learning study, biology teachers established a community of practice. They learned content and prepared lesson plans together. Moreover, they evaluate their own and each other's classroom practice after the implementation of the lesson plans. The results suggest that the intervention was effective in changing the teachers' teaching orientations towards more student-centered ones as well as their assumptions of the best teaching methods of evolution.

Burton (2013) designed a professional development program for science teachers that focused on student work. Science teachers met each week during a 5-month period. The science teachers collaboratively design lesson plans and enact them. After the enactments, they bring three student work of different levels to the PD sessions. By collaboratively analyzing the student work, participating teachers

made comments about the effective and ineffective characteristics of the lessons. Finally, each wrote a reflection paper based on the practices in the teacher group. The results of the study suggested that participating teachers' lessons became more student-centered which reflects characteristics of inquiry. In another study, Roth et al. (2011) established a community of practice in which they used video recordings of the lessons. The science teachers made an inquiry into their own teaching by using these videos as learning tools. Furthermore, they made reflections as well as discussions. The intervention was found to be effective on teachers' PCK as well as student outcomes.

Forsler, Nillson and Walan (2024) examined the influence of a professional development program that combines CoRe's with video-based reflections. Throughout the program, secondary school teachers prepared CoRe's about sustainable development and made video-based reflections. After preparing CoRe's and watching videos, interviews were also made with the teachers. The results of the study suggest that teachers become more aware of the characteristics of their lessons that can promote sustainable development. The researchers indicated that this awareness was the result of the professional development program that made teachers' own instruction explicit for them.

Several studies investigated the influence of online professional development programs. Wong et al. (2023) designed an online platform which integrates STEM (science, technology, engineering and mathematics) learning with arts. Teachers could watch videos of STEAM (science, technology, engineering, arts and mathematics) instruction, interact with several scenarios that aim to promote student engagement and logs that enable them to write reflections. Furthermore, teachers could use several tools that probe discussions among teachers. The results of the

study suggest that teacher's self-efficacy beliefs regarding teaching STEM increased. In another study, Wang, Liu and Tong (2023) investigated the development of teachers' PCK as they engage in an online program. The researchers aimed to establish a professional learning community. Throughout the program, a variety of collaboration techniques were used. The researchers indicated that teachers who newly entered the profession capitalized most from the intervention.

In another study, Eltanahy and Mansour (2024) investigated the impact of a professional development program that aims to enhance teachers' entrepreneurial literacy as well as their knowledge to integrate entrepreneurial literacy into instruction. The professional development program consisted of several sections such as verbal explanations regarding the meaning and importance of entrepreneurial literacy, hands-on activities, group work and group discussions. The researchers indicated that the professional development program significantly contributed to pedagogical growth of the teachers. In a similar vein, Harrell, Thompson and Waid (2023) investigated the influence of a professional development program with a theme of 5E learning. During a yearlong professional development program, science teachers of eight grades participated in professional development activities that aim to enhance their knowledge to use 5E learning in their instruction. A test that aims to measure science teachers' content knowledge as well as reflections were used as data sources. The results of the study suggest that participant teachers' content knowledge increased after they attended the professional development program. Furthermore, as analyzed from their reflection papers, teachers started to use more student-centered strategies, elicit prior knowledge, and use formative assessment as they progressed in the program.

Wongsopawiro, Zwart and van Driel (2017) designed a professional development program for middle and high school science teachers. During the program, teachers learnt about action research and further encouraged to conduct action research on their own teaching. Teachers made literature reviews about student difficulties and alternative instructional methods for a topic they had chosen. Then they design action research under the supervision of science education researchers. The results of the study suggest that teachers enhanced their repertoire of student conceptions by conducting literature review and making discussions with colleagues. Furthermore, teachers who reflect on their own teaching in terms of student understanding could select to the point instructional strategies that address student difficulties.

2.3.5 The development of measurement tools that aim to measure PCK

The final research area of PCK is about the development and validation of tests that aim to measure teachers' PCK. PCK tests were developed in a variety of subjects such as science, chemistry, physics, and biology. The tests were generally developed in a written format for either preservice or in-service teachers. The tests also usually focused on a specific topic of a subject. Statistical analysis such as confirmatory factor analysis (CFA), exploratory factor analysis (EFA), Rach or IRT are used to validate the instruments. For example, Kirschner et al., (2016) developed a paper and pencil test to assess physics teachers' professional knowledge. The researchers used a model of professional knowledge that consists of knowledge areas, topics and facets. The knowledge areas cover declarative, procedural and conditional knowledge whereas facets include knowledge of student understanding and knowledge of instructional strategies. The physics topic for the test was mechanics.

The items were mostly open-ended and written in the format of vignettes. The researchers ensured the content validity of the test by using a model and consulting experts. The construct validity of the test is checked by comparing PCK scores of physics teachers with pre-service teachers, physicists, and non-physics teachers (chemistry, biology etc.). They ensured the structural validity of the test by computing Rasch analysis and indicated that CK, PCK and PK are all distinct dimensions of professional knowledge. They indicated that the instrument they developed is valid and reliable to assess physics teachers' PCK.

Großschedl et al. (2019) developed another paper and pencil test to assess biology preservice teachers' PCK-IBI (the Pedagogical Content Knowledge in Biology Inventory). The researchers based their instrument development process on a transformative model of PCK. They used the knowledge areas of declarative, procedural and conditional as well as PCK facets of knowledge of student understanding, knowledge of instructional strategies, classroom management and learning assessment. To ensure the construct validity of the scale, the researchers investigated the interrelations between PCK and other related variables such as cognitive abilities, subject matter knowledge, pedagogical knowledge, motivation to choose teaching profession and epistemological beliefs about teaching and learning. The results of their study suggest that PCK-IBI is a valid and reliable instrument to measure preservice biology teachers' pedagogical content knowledge.

Park et al. (2018) developed a PCK survey to measure high school science teachers' pedagogical content knowledge of photosynthesis. They used the Pentagon model of PCK as a framework of their study. In the item construction process, they focused on two components of pedagogical content knowledge: (1) knowledge of students' understanding and (2) knowledge of instructional strategies. These

components are widely used in most of the PCK assessment studies since they are regarded as the most critical ingredients of PCK (Loughran et al., 2006). During the development process of the instrument, the researchers extensively reviewed literature about students' conceptions, analyzed relevant curriculum materials, recorded videos of science teachers and analyzed student work. After they designed initial items, they constantly engaged in discussions with experts and teachers. In their final implementation, the instrument consists of classroom scenarios that require teachers to identify student difficulties and misconceptions, explain reasons why students might have these difficulties and offer instructional strategies to overcome these student difficulties. The results of their study suggest that the PCK survey they developed has sufficient validity and reliability.

Bahçivan (2012) conducted a study to assess in-service physics teachers' pedagogical content knowledge of electricity. Additional variables such as self-efficacy beliefs, job satisfaction, attendance to in-service training and years of experience were analyzed in relation to physics teachers' pedagogical content knowledge. The researcher designed the PCK test in a form of open-ended questions. The questions depict classroom scenarios that describe students' typical difficulties and misconceptions about electricity concepts. The researcher utilized the most critical components of pedagogical content knowledge as the framework of the test development process: Knowledge of student understanding and knowledge of instructional strategies and representations. The instrument is implemented to 278 physics teachers throughout Turkey. Results of the exploratory and confirmatory analysis indicated that the instrument is valid in terms of assessing in-service physics teachers' PCK of electricity. Further analysis also indicated that in-service physics teachers' PCK of teaching electricity is predicted by their self-efficacy beliefs and

attendance to training programs. However, years of experience and job satisfaction were not significant predictors of their PCK.

2.4 Data sources used in PCK investigations

Four main data sources are used in PCK investigations. PCK researchers use classroom observations, interviews, work obtained from teaching, and written instruments while they investigate PCK of teachers (Chan & Hume, 2019).

2.4.1 Observations

Observations are generally made by video recording the enactment of the classroom teachings (Marshall, Smart & Alston, 2016; Park et al, 2018). In a study, Alonzo, Kobarg and Seidel (2012) investigated pedagogical content knowledge of physics teachers by analyzing video recordings of classroom interactions between the teachers and students. The researchers justified their use of observations as a data source for various reasons. The context specific characteristic of the PCK, the researchers indicated, can be captured in an environment which is the most relevant: classrooms. It was also indicated that, since PCK is regarded as implicit, observations do not necessitate the construct to be verbally expressed by the teachers. The researchers video-recorded two classrooms to reveal the differences between high and low-achiever students' classroom interactions. The specific focus of the observations was teachers' utilization of content knowledge in class interactions. The researchers coded the video-recorded observations in terms of several aspects such as learner-centeredness and flexibility. Specifically, video segments of positive and negative examples of each instance of the codes were identified and counted for each teacher. The results of their study suggest that students of the teacher who used more

learner-centered approaches and flexible representations of the content tend to perform higher.

Several researchers used observations as data sources to reveal the interrelations between PCK and teacher instruction (Park et al., 2011; Barendsen & Henze, 2017). Park et al. (2011) investigated whether PCK is necessary for reformed instruction of science. The researchers measured both PCK and reformed instruction of science with observations. The reformed instruction of science was measured with The Reformed Teaching Observation Protocol (RTOP). The tool requires the observer to describe the classroom environment, activities that are used, structure and the implementation of the lesson and the interactions between students and the teachers. PCK of the teachers was used with a rubric that quantifies classroom observations. Specifically, observations were made for two dimensions of PCK namely knowledge of student understanding and knowledge of instructional strategies. Each dimension of PCK was divided into several subdimensions and teachers' performance was classified from limited to exemplary for each sub-dimension. For example, teachers' knowledge of student understanding was subdivided into knowledge of learning difficulties and knowledge of misconceptions. When teachers displayed a sophisticated understanding of student misconceptions, their performance was classified as exemplary. The results of the study suggest that biology teachers' PCK is significantly correlated with reformed instruction of science.

2.4.2 Interviews

Interviews are another data source used in PCK research. In interviews, either a set of questions are directly asked or tools such as video recordings or CoRe's were used

to stimulate teacher answers. For example, Salloum (2008) investigated chemistry teachers' PCK of chemicals. The researcher used a set of questions that probe teachers' articulation of their own way of teaching and understanding of student conceptions. Alonzo and Kim (2016) used video-based interviews to investigate how declarative knowledge is transformed into dynamic knowledge during instruction. The researchers first video-recorded classroom teachings of the teachers. Then they purposefully selected several segments of the recordings to use in the interviews. These video segments were used in the interviews specifically to elicit and elaborate teachers' knowledge of student understanding and knowledge of instructional strategies. As teachers watched videos of their own teaching, they were expected to reason and justify their pedagogical moves during the interviews. The results of the study suggested that teachers' declarative knowledge as well as their orientations to science teaching direct their dynamic PCK displayed in classrooms.

In another study, Adadan and Oner (2014) investigated how preservice teachers' PCK of behavior of gases progressed during a methods course. In the context of their study, CoRe's served as a tool to stimulate preservice teachers' responses during interviews. The preservice teachers were first expected to verbally prepare a tool. The tool required them to think about issues such as the importance of the topic, student misconceptions about the topic and instructional strategies that point out the student misconceptions. The researchers also asked further questions to elicit preservice teachers' elaborations. Finally, the progression from the analysis of the first interviews to the final interview at the end of the semester was compared to reveal the progression of the preservice teachers.

Findlay and Bryce (2012) also investigated preservice physics teachers' PCK by conducting interviews. The researchers used classic experiments as a context for

their interviews. Preservice teachers are first introduced to the experiments and then asked to elaborate on how those experiments could be used to enhance student learning as well as elicit student understanding. Several student statements reflecting alternative conceptions are also introduced and preservice teachers are asked to elaborate on which instructional moves they would take. In another study, Krepf et al. (2017) investigated physics teachers' PCK by showing segments of video recordings of their own instruction to the teachers. The researchers purposefully chose video segments that illustrate positive or negative examples of choice of instructional strategies as well as a grasp of student understanding. After watching each segment, teachers were asked to elaborate on what they observed in the segment.

2.4.3 Work obtained from teaching

Work obtained from teaching or teaching artifacts is another data source used in PCK research. Lesson plans and reflection papers can be considered different forms of teaching artifacts (Demirdöğen & Uzuntiryaki-Kondakçi, 2013; Käpylä et al., 2009). For example, Demirdöğen and Uzuntiryaki-Kondakçi (2013) investigated the influence of a methods course emphasizing PCK and the nature of science. To investigate the influence of the course, researchers used lesson plans and reflection papers as data sources. The preservice teachers wrote reflection papers after they attended lessons about the nature of science. They were guided by several open-ended questions such as what they thought the message of the lesson was and how the lesson might influence their approach to science education. Furthermore, the lesson plans the preservice teachers prepared at the beginning and at the end of the course were also used as data sources.

In a study that investigates the influence of a professional development program on project-based learning, Kanter and Konstantopoulos (2010) used written essays as a data source along with others. Teachers first watch the video recordings of their own teaching. Then they were expected to write an essay that points out several issues such as possible student understanding conveyed in the classroom interactions, reasons that might lead students to think that way and possible instructional moves that are relevant to that specific student understanding. In another study, Kellner et al. (2011) used Lesson Preparation Method to elicit preservice teachers' knowledge of student understanding. The preservice teachers were expected to fill out a lesson plan template with several guiding questions such as students' difficulties and misconceptions about the topic and possible instructional strategies that might be used to overcome these difficulties.

2.4.4 Written instruments

Written instruments used to investigate PCK consist of questionnaires of open-ended questions, surveys with Likert-type items and tests with closed-ended and/or open-ended items (Chan & Hume, 2019). For example, Stasinakis and Athanasiou (2016) used a Likert type instrument to assess Greek teachers' teaching of evolution which they regarded as PCK. The instrument contained several statements about student understanding of evolution as well as instructional strategies that can be used in lessons. The teachers were expected to indicate to what extent they agreed with the statements. In another study, Stender et al. (2017) investigated how PCK is transformed into enactments of lessons. The researchers used an instrument that consists of multiple-choice questions for the topic of mechanics. Kirschner et al. (2016) used an instrument that consists of vignettes in a form of open-ended

questions. The researchers provided teachers with an authentic description of classroom events or interactions. The questions were asked based on these authentic scenarios.

In several studies, open-ended questions in written form were given to the teachers. The researchers made thematic analyses of the responses or classified the responses in terms of accuracy. For example, Kind (2017) examined preservice science teachers' PCK with three open-ended vignettes that requested them to propose instructional strategies that elicit student misconceptions. Preservice teachers' responses were coded in terms of their correctness and relevancy. Below a detailed review of the written instruments is presented.

2.5 A review of studies that investigate PCK with written instruments

In this section, a systematic literature review of the studies that investigate teachers' PCK with written instruments is presented. Specifically, studies that investigate middle school and high school teachers' PCK in the field of science education are reviewed. The PCK studies using written instruments were reviewed based on the following themes: Topic of the test, publication year, type of the written instruments, characteristics of the sample, PCK models, dimensions, response format, number of items and evidence collected to ensure the validity and reliability of the test'.

ERIC and Online Wiley Library databases were used while searching the articles. Pedagogical content knowledge (PCK) and science education keywords were used during the search process. Since peer-reviewed articles undergo a review process, they can be regarded as quality data sources (Henderson, Beach & Finkelstein, 2011). For this reason, only peer-reviewed articles were included in this review. The review covers studies published up to May 2024. After the initial search,

over 300 articles were obtained. By applying the inclusion and exclusion criteria, 40 articles were investigated in total. The codes and references of the articles are presented in APPENDIX B.

Inclusion criteria of the articles:

- Published in peer-reviewed journals
- Conducted in the field of science education
- Using written data sources
- Measuring pre-service, middle school and high school teachers' PCK

Exclusion criteria of the articles:

- Conducted in fields other than science education
- Investigating primary school or professor's PCK
- Investigating teachers' technological pedagogical content knowledge (TPACK)
- Using no written instruments (such as using only observations or interviews as data sources)

A summary of the studies in terms of the predetermined themes is presented below. For each study, topic, year, type, sample characteristics, PCK model, response format, evidence used to ensure validity and reliability are coded. In several studies, the researchers did not mention any statements about several of the themes. In this situation, the code of 'not specified' was used.

2.5.1 Topic of the PCK test

Most of the studies that use written instruments were conducted in the field of biology (See Table 1). The percentage of studies using written instruments was 22 % for physics and 12 % for chemistry. The percentage of studies developed in the

subject of middle school science was 15%. While several tests were developed for a single topic (e.g. floating and sinking), several other tests were developed for multiple topics (e.g. ecology, evolution, genetics and physiology). The most studied topic in physics was mechanics. Ecosystem and photosynthesis were the most studied topics in the field of biology.

Table 1. Topics of the PCK Tests

Subject	Topic	n	%
Science (5)	Nature of science	5	12.5
	Photosynthesis		
	Particle nature of matter		
	Newton's 3rd law		
Physics (9)	General	9	22.5
	Explanation		
	Electricity		
	Electric field		
	Electromagnetics		
	Optics		
	Mechanics		
	Newton's laws of motion		
	Force and motion		
	Floating and sinking		
	Heat and temperature		
Chemistry (5)	Organic chemistry	5	12.5
	Stochieometry		
	Particle nature of matter		
	Chemical equilibrium		
	Reaction rate		
Biology (19)	General	19	47.5
	Ecosystem		
	Genetics		
	Evolution		
	Photosynthesis		
	Blood and the human cardiovascular system		
	Cell		
General (2)	Scientific experimentation	2	5
	Argumentation		

2.5.2 Publication year

The number of PCK studies using written instruments has tended to increase in the last ten years (See Table 2). This increase has reached its peak value in 2017.

Table 2. Distribution of the Test Development Studies by Year

Year	n
2008	2
2009	1
2012	1
2013	5
2014	2
2015	3
2016	6
2017	10
2018	0
2019	4
2020	1
2021	1
2022	1
2023	2
2024	1

2.5.3 Type of the written instruments

The analysis of the written instruments reveals that three types of written data sources were used (See Table 3). In one type of instrument, researchers developed open-ended questions and implemented them to the participants in a form of a questionnaire. In these studies, constant comparison analysis or descriptive statistics were generally used to analyze data. The second type of instrument was the Likert type and required the participants to indicate their agreement with several statements. Finally, the third type of instrument are tests that include open-ended and/or closed-ended questions. In these studies, different from the questionnaires, statistical analysis such as item analysis, EFA and CFA were used. A summary of the types of written instruments is presented in Table 3.

Table 3. Type of Written Instruments

	n	Study code
Questionnaires consisting of open-ended items	10	24, 25, 26, 28, 29, 31, 32, 33, 37, 40
Surveys with Likert type format	2	34, 35
Tests with open-ended and/or multiple-choice items	28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 27, 30, 36, 38, 39

Questionnaires that consist of open-ended items generally requested teachers to write their ideas about specific student difficulties and possible instructional strategies that elicit them. In several studies, the questions were written in a vignette form to make the context more authentic for the teachers. For example, Kind (2017) used vignettes in her questionnaire to probe teachers' PCK. The researcher used content analysis to analyze responses of the teachers. In another study, İnaltekin and Akçay (2021) examined preservice physics teachers' knowledge of student understanding with 5 open-ended questions. The items in the questionnaire illustrated several student responses to physics questions and the preservice physics teachers were expected to examine the quality of the answers. In this study, preservice teachers' responses were classified into several categories such as exemplary, acceptable and weak.

The second type of instruments were surveys that requested teachers to indicate their agreement with certain statements. There were only two studies that used surveys to assess PCK of teachers. In a study in which the interrelations between Greek teachers' attitudes to evolution and their PCK was investigated, a survey with a Likert-type response format was used. The teachers were expected to rate their agreement with statements such as "During my teaching I mainly imitate the way I was taught in my school years" and "When I teach evolution, I mainly use the material contained in the textbook".

The third type of written instruments were tests developed to measure teachers' PCK. Most of the studies utilizing written instruments were test development studies (n=28). In this type of instruments, items could be both open-ended and closed-ended. Statistical analysis such as EFA, CFA or Rasch analysis were used to establish the validity and reliability of the tests.

In most of the studies, the format of the test items is not specified (See Table 4). In this review, the format implies the structural flow of the items. Only 18 % of the studies explicitly identified the format of the test items. In four of these studies, the test items are developed as 'vignettes' whereas in three studies the test items are developed in a 'scenario-based' format. Although the researchers used different names to characterize items, the core characteristics of the shared items were similar. Both vignettes and scenario-based items that were shared were authentic in terms of representing real classroom environments. In several of the studies, although the format of the items is not specified, the characteristics of the shared items represent vignettes or scenario-based items. However, several tests adopt a more direct approach while assessing PCK. In these studies, no classroom context is described, and teachers are required to give direct answers to the questions such as naming common misconceptions about sinking.

Table 4. Descriptive Statistics of the Format of the Test Items

	n	Study code
Vignette	4	10, 14, 29, 37
Scenario-based	3	5, 12, 20
Unspecified	33	

2.5.4 Characteristics of the samples

The characteristics of the samples were analyzed in terms of both sample group and sample size (See Table 5). In nearly half of the studies, the sample group was in-service teachers (n=21). In 35% of the studies, the sample group was pre-service teachers. In 13 % of the studies, multiple groups of teachers or scientists participated in the studies mostly for validation purposes.

Table 5. Sample Groups of the Studies

	IST	PST	IST+PST	IST + science experts	IST + PST + science experts
n	21	14	3	1	1
%	52.5	35	7.5	2.5	2.5

IST:In-service teacher, PST: Pre-service teacher

The sample size of the studies ranged from two to 495 (See Table 6). The number of studies with a sample ranging from one to ten are six. Most of the studies had a sample size ranging from one to 50 (n=15). Only one study had a sample greater than 300.

Table 6. Sample Size of the Studies

	1-10	11-50	51-100	101-200	200-300	300+
n	6	9	8	13	3	1
%	15	22.5	20	32.5	7.5	2.5

2.5.5 PCK models that are used in the written instruments

In most of the studies, the model that is developed by Magnusson, Krajcik and Borko (1999) was used (n=22). The second most used model was Gess Newsome's topic-specific professional knowledge (TSPK) model (n=8). In one study the PCK model

by Tamir was used. The remaining studies did not make any specifications regarding the model that they used.

2.5.6 Dimensions of the written instruments

Most of the PCK studies that use written instruments investigated knowledge of student understanding and knowledge of instructional strategies together (n=15). There were three studies that just investigated knowledge of student understanding and one study that just investigated instructional strategies. Five studies focused on all the dimensions of PCK including orientations to science teaching. Curriculum knowledge and assessment knowledge are the PCK dimensions that were least analyzed (See Table 7).

Table 7. Dimensions Analyzed in the Studies

	n	%	Study code
Student Understanding	3	7.5	35, 39, 40
Instructional Strategies	1	2.5	34
Student understanding + Instructional strategies and representations	15	37.5	4, 6, 7, 8, 10, 14, 15, 18, 20, 21, 27, 29, 30, 32, 33
Student understanding + Instructional strategies and representations + Curriculum	7	17.5	3, 9, 11, 16, 19, 36, 38
Student understanding + Instructional strategies and representations + Assessment	3	7.5	2, 22, 23
Student understanding + Instructional strategies and representations + Assessment + Curriculum	5	12.5	1, 12, 13, 17, 31
Student understanding + Instructional strategies and representations + Curriculum + Assessment + Orientations to science teaching	5	12.5	24, 25, 26, 28, 37
Assessment	1	2.5	5

2.5.7 Response format of the written instruments

The response format of the instruments implies whether the items have a closed-ended or open-ended response format. In more than half of the written instruments

(n=23), only open-ended items are used (See Table 8). In 15 instruments, both open-ended and closed-ended items are used. Just in two studies, only closed-ended items are used.

Table 8. Item Types that are Used in the Tests

	Closed-ended	Open-ended	Both closed-ended and open-ended
n	2	23	15
%	5	57.5	37.5
Study code	23, 34	1, 3, 5, 7, 9, 11, 12, 16, 17, 19, 20, 24, 25, 26, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 40	2, 4, 6, 8, 10, 13, 14, 15, 18, 21, 22, 27, 30, 39

2.5.8 Number of items in the written instruments

In nearly half of the studies, (n=18), one to 13 items are used in the written instruments (See Table 9). In several of these studies, the test items have several sub-questions. In one study, the PCK test consisted of 66 multiple-choice and short answer questions. In 7 studies, the number of the items in the instruments was not specified.

Table 9. Number of Items of the Written Instruments

	1-13	14-25	26-40	41-67	Not specified
n	18	10	3	2	7
%	45	25	7.5	5	17.5

2.5.9 Evidence collected to ensure the validity of the test:

In more than half of the articles (n=24), evidence to ensure the content validity of the instruments was collected (See Table 10). In all these studies, content validity was established by consulting experts. In most of the studies (n=25), evidence of

construct validity was collected. Construct validity was ensured by using statistical techniques such as CFA, Rasch and IRT models.

Table 10. Types of Validity Collected as Evidence in the Studies

	n	%
Content validity	24	60
Criterion validity	4	10
Convergent validity	5	12.5
Construct validity	25	62.5
Face validity	4	10
Triangulation	3	7.5

In several studies, researchers checked convergent validity to ensure construct validity of the test. For example, Großschedl et al. (2015) conducted a correlational analysis between teachers' PCK and cognitive ability to check for convergent validity. Researchers also checked for construct validity by comparing known groups. Specifically, PCK scores of science teachers and non-science teachers were compared in most of the studies. For example, Ergönenç et al. (2014) compared the PCK test scores of physics and non-physics teachers as well as physicists to ensure the construct validity of their PCK test for physics. Großschedl et al. (2019) compared the PCK scores of in-service and pre-service teachers whereas Joachim et al. (2020) compared PCK scores of students at the graduate level and students at the undergraduate level. In Kirschner's (2016) study, teachers who teach different subjects (physics vs. math, chemistry and biology) were compared in terms of their PCK scores as a way of ensuring construct validity. The researchers also compared pre-service and in-service physics teachers' PCK scores to provide further validation. Finally, Schmelzing (2013) compared experienced biology teachers' PCK scores with biologists to provide evidence for construct validity.

Several studies in which open-ended questionnaires were used reported about establishment of triangulation. For example, Demirdöğen (2016) established triangulation by using multiple data sources such as questionnaires, surveys, and interviews. Thus, the researcher contributed the credibility of the findings of her study.

2.5.10 Methods to ensure the reliability of the test

To ensure the reliability of the written instruments, mainly two types of reliability were analyzed: Internal consistency reliability and interrater reliability (See Table 11). In most of the articles, internal consistency reliability analysis was carried out (n=27). In a slightly low number of studies, intercoder reliability was calculated (n=13).

Table 11. Types of Reliability Analyzed for Written Instruments

	n	%
Internal consistency	27	67.5
Intercoder reliability	13	32.5

Depending on the general analysis method of the studies, internal consistency coefficients range from Cronbach's alpha reliability coefficient to a posteriori/plausible value (EAP/PV) reliability value as well as from Person Separation Index to item and person reliability values. The reliability coefficient values obtained from the tests are presented in Table 12.

Table 12. Internal Reliability Coefficient Values of the Tests

	.60-.69	.70-.79	.80-.89	.90+
Cronbach's alfa reliability coefficient	3	2	3	1
EAP/PV value	2	1	1	
Item reliability		1		3
Person reliability	1	2	1	
Others			2	

2.5.11 Summary of the studies that use written instruments to examine PCK

Most of the written instruments were developed in the field of biology. The number of instruments that measure physics and chemistry teachers' PCK is slightly low. One of the main findings of this review is that the researcher approached differently to the topic-specific nature of PCK. While several studies are developed for a single topic (e.g. sinking and floating), several other studies are developed for more than one topic (e.g. ecology, evolution, genetics and physiology). In several of the studies, the topic or topics of the tests are not specified.

There were three types of written instruments used in PCK research. Many of them were tests consisting of multiple-choice and/or open-ended items. The psychometric properties of these tests were established by analyses such as EFA, CFA, IRT or Rasch. The second mostly used written instruments were questionnaires consisting of open-ended items. Constant comparison analysis, coding and descriptive statistics are used in these studies. The least used written instruments were scales with Likert-type response formats.

In none of the studies, the sampling method is explicitly identified. As Fraenkel, Wallen and Hyun (2011) indicated, simple random sampling is a way to ensure the generalizability of the research findings. In this regard, this ambiguity leads to questions about the generalizability of the findings of the studies. Furthermore, in most of the studies the sample size is low. Only in two studies, the

number of participants is higher than 200 whereas in six studies the number of participants is lower than 50. This may stem from the difficulty to achieve teachers during the data collection process compared to other sample groups such as students. This may be problematic since low sample sizes may decrease the power as well as the reliability of the tests (Delice, 2010).

In most of the studies, the sample group consists of in-service teachers. There are only five studies that have multiple groups of participants such as in-service teachers, pre-service teachers, non-science teachers and science experts with no teaching certificates. These studies justified the use of multiple sample groups to ensure the validity of the test.

In most of the studies, the format of the test items is not specified. In only seven studies, the format of the test items is identified as vignettes (n=4) and scenario-based (n=3). As Brovelli et al. (2014) indicated, writing authentic test items that reflect classroom context is important to ensure the validity of an instrument that measures teachers' PCK. In this regard, it is important for researchers to explain the item formation process as well as item format of the test.

Regarding the validity issues of the tests, nearly half of the studies consulted experts to ensure the content validity of the tests. In more than half of the studies, statistical analyses are conducted to ensure the construct validity of the tests. Discriminant and convergent validity, as well as criterion-related and face validity are the least used validity types in the studies. This may stem from the popularity of CFA or Rasch analysis compared to other ways to ensure the construct validity of a test (Gül & Sözbilir, 2016).

2.6 The summary of the literature review

In this section, a literature review of PCK is presented. Specifically, conceptualization, core characteristics, models and assessment of PCK are elaborated. Furthermore, a literature review of investigation of PCK is made. Specifically, literature about the nature and development of PCK, PCK change as a result of interventions and PCK test development studies are reviewed. In addition, research findings that demonstrate the interrelations between PCK and other teacher-related variables are presented. Data sources used in PCK studies are also elaborated. Four main data sources namely observations, interviews, work obtained from teaching and written instruments are presented. Since this study aims to develop a written instrument that aims to portray physics teachers' PCK of heat and temperature, a systematic review of research studies that use written instruments was made.

Researchers highlight the importance of measuring teachers' pedagogical content knowledge due to its critical role in student outcomes. Qualitative and quantitative methodologies are intensively used depending on the purposes of researchers. Specifically, researchers who aim to capture PCK use classroom observations and interviews as main data sources. These studies provide a detailed description of PCK as it is investigated in-action (Park et al., 2018). Although these data sources illuminate the structure of PCK in a detailed manner, they cannot be used in larger samples due to the cost. Instruments that quantitatively measure PCK, on the other hand, focus on PCK on-action and can be used on a larger scale (Park et al., 2018). Although a variety of quantitative instruments are developed for the domain of mathematics, such instruments are rare in the domain of science. With this regard, this study aims to develop a written instrument that assesses physics teachers'

pedagogical content knowledge. Given the topic-specific nature of PCK, the topic of the instrument was selected as heat and temperature.

CHAPTER 3

METHODOLOGY

This section explains the research design, population and sample, description of the instrument, procedure, and the data analysis methods of the study. Since this study aims to develop a written instrument to assess in-service physics teachers' PCK of heat and temperature, a detailed description of the design of the instrument, phases of the instrument development process, format of the instrument, and rubric preparation is presented.

3.1 Research design of the study

A survey design was used in this study. Survey design is used to describe certain characteristics of a population such as attitudes, beliefs, or knowledge (Fraenkel et al., 2011). This study aims to assess in-service physics teachers' PCK of heat and temperature by developing and using a written instrument. Various data collection methods, such as the administration of an instrument or interviews could be used in survey designs (Fraenkel et al., 2011). Throughout this study, various rounds of cognitive interviews were conducted with the teachers. Finally, a test that consists of both open-ended and closed-ended items was administered to in-service physics teachers. The instrument was developed according to the instrument development framework by Hill et al. (2004) and Hill et al. (2008) who developed a PCK assessment in mathematics.

3.2 Population and sample

The target population of this study is all in-service physics teachers in İstanbul. The instrument development process was conducted through different iterations (cognitive interviews and final implementation). In this regard, the sample of this study consists of 109 teachers in total. For validation purposes, seven teachers of other subjects (i.e., chemistry or biology) as well as 3 pre-service physics teachers participated in the study. A convenience sampling method was used to choose the participants of the study. Although convenience sampling decreases the likelihood of choosing a representative sample, it has several advantages such as inexpensiveness and easiness in achieving the samples (Fraenkel et al., 2011). To decrease the burden of achieving a high number of participants, a convenience sampling method was used in this study.

Throughout the study, various rounds of cognitive interviews were conducted, and a written instrument was administered. The number and fields of the teachers who participated in each phase of the study are presented in Table 13.

Table 13. Number and Fields of Participant Teachers

	The first round of cognitive interviews	The second round of cognitive interviews	Implementation of the test
Physics	4	5	90
Non-physics	5	2	-
Pre-service physics	-	3	-
Total	9	10	90

The final version of the PCK test was implemented to 90 in-service physics teachers from 15 different districts of İstanbul named Bahçelievler, Bakırköy, Bayrampaşa, Beşiktaş, Beyoğlu, Esenler, Eyüpsultan, Gaziosmanpaşa, Güngören, Kağıthane, Şişli,

Üsküdar, Ümraniye and Zeytinburnu. The data was collected during the second semester of the academic year of 2022-2023. There was a total of 66 Anatolian high schools in these districts. The researcher visited 51 of these high schools and collected data from 43 high schools. In most of these schools, there were only one or two physics teachers. The teaching experience of the physics teachers ranged from four to 35 years with a mean of 19 years (See Table 14). 50 of the physics teachers were male and 40 of the physics teachers were female. All the physics teachers work in private or state schools that are affiliated with the Ministry of National Education (MoNE). Fourteen of the physics teachers work in private schools whereas 76 of the physics teachers work in state school. While 32 of the physics teachers have a master's degree, 59 of the physics teachers have a bachelor's degree, and one physics teacher has a PhD degree.

Table 14. Learning Experiences of the Physics Teachers

Min	Max	Mean	Median	Mode
4	35	19	20.5	22

3.3. Instrument

The main instrument used in the study was developed throughout the study. Following is a detailed explanation of the overview of the instrument, phases of the instrument development process and format of the instrument.

3.3.1 Overview of the PCK of heat and temperature instrument

The PCK of heat and temperature instrument is a paper and pencil test that probes in-service physics teachers' PCK. Given the topic-specific nature of PCK, the topic of the instrument was selected as heat and temperature. Heat and temperature is a 9th

grade topic that constitutes 20% of the program in terms of class hours. In this regard, portraying physics teachers' PCK of heat and temperature is of importance. In addition, heat and temperature is a fruitful topic in terms of the literature on students' understanding and instructional strategies which constitute significant components of teachers' PCK. Teachers were also found to face challenges in internalizing heat and temperature concepts (Jasien & Oberem, 2002). Given the importance of teachers' PCK on student outcomes, the portrayal and assessment of physics teachers' PCK of heat and temperature might suggest implications for the efforts to enhance teacher knowledge.

There are a high number of studies that portray students' difficulties and misconceptions regarding the heat and temperature concepts. Several student difficulties and misconceptions are as follows:

- heat and temperature concepts cannot be differentiated from each other (Shayer & Wylam, 1981; Linn & Songer, 1991),
- heat capacity and specific heat are confused (Linn & Songer, 1991),
- heat transfer mechanisms are hardly differentiated (Lewis & Linn, 1994),
- poor conceptions of state changes such as evaporation and condensation are formulated (Osborne & Cosgrove, 1983),
- heat is conceptualized as a substance (Shayer & Wylam, 1981),
- temperature increases during state changes (Osborne & Cosgrove, 1983),
- heat is an internal property of objects (Osborne & Cosgrove, 1983; Linn & Songer, 1991)

Furthermore, a variety of instructional methods and strategies can be used to teach heat and temperature. Several scientific practices that can be utilized by teachers in their instruction are as follows:

- making observations and measurements,
- planning investigations,
- analyzing and interpreting data,
- developing models,
- conducting design projects (NGSS, 2013).

The instrument focuses on various sub-topics of heat and temperature explicated in the MoNE curriculum, such as heat and temperature (specific heat, heat capacity, thermometers), phase changes, thermal equilibrium, and ways of heat transfer. The test was initially designed to assess three dimensions of PCK: (1) knowledge of student understanding, (2) knowledge of instructional strategies, and (3) knowledge of curriculum. After conducting the cognitive interviews, the dimension of knowledge of curriculum was excluded from the test. The final implementation of the written instrument focused on the following two dimensions of PCK: Knowledge of student understanding and knowledge of instructional strategies. These dimensions were the most studied in the literature. Furthermore, they were found to be the strongest predictor of the coherence of the professional knowledge of the teachers (Park & Chen, 2012). The final instrument consists of 24 items, with 12 items examining Knowledge of Student Understanding and 12 items examining Knowledge of Instructional Strategies. The format of the items was vignettes.

3.3.2. Phases of the instrument development process

The instrument development framework of this study is informed by the work of Hill et al. (2004) and Hill et al. (2008) who developed a PCK assessment in mathematics. The authors utilized three main phases throughout their PCK assessment

development: Conceptualization of the domain, development of initial items, and field testing. According to the researchers, the model they have used in their study "…ultimately connects all three pieces of this work, tying conceptualization directly to the specification of items, and tying results from field tests back to strengths and weaknesses of the initial conceptualization" (2008, p. 373). In the current study, these three main phases were also utilized throughout the instrument development process. Specifically, the researcher conceptualized the domain of PCK, developed an initial set of items, pilot-tested the items with teachers, conducted cognitive interviews, made necessary revisions in items, and implemented the final version of the instrument (See Table 15).

Table 15. The Instrument Development Process

Phase	Description of the phase
1. Conceptualization of PCK	-The components of PCK are identified to develop the items of PCK- H&T instrument.
2. Development of preliminary items	-Development of 13 items
3. First round of cognitive interviews	-Conducting cognitive interviews with 9 teachers to investigate whether the instrument items could differentiate between physics and non-physics teachers
4. Development of a comprehensive item pool	- By conducting an extended literature review and evaluating the results of the first round of cognitive interviews, an item pool that consists of 53 items was developed.
5. Second round of cognitive interviews	-Conducting cognitive interviews with 10 teachers to investigate whether the instrument items could differentiate between physics, non-physics and pre-service teachers
6. Development of the PCK- H&T test	-Informed by the results of the second round of cognitive interviews, the first version of PCK- H&T instrument consisting of 24 items was constructed. - Expert opinions were taken to ensure content validity.
7. Administering the PCK- H&T test	-The PCK- H&T instrument is administered to 90 in-service physics teachers
8. Conducting descriptive statistics and presenting results	-Descriptive statistics was used. -Categories about the responses were developed. Correct, partially correct and false/irrelevant. -Percentages of teachers from each category were calculated.

In the first phase, the domain of the instrument was conceptualized. The PCK is conceptualized by consulting the widely used PCK models in literature. PCK is generally conceptualized as consisting of four dimensions: (1) Knowledge of student understanding, (2) knowledge of instructional strategies and representations, (3) knowledge of curriculum and (4) knowledge of assessment. However, most of the studies in literature generally focused on two or three dimensions of PCK (Großschedl et al., 2019; Jüttner et al., 2013; Ergönenç et al., 2014; Kirschner et al., 2016; Mahler et al., 2017; Mc Neill et al., 2016; Meschede et al., 2017; Monet et al., 2008; Park et al., 2018; Smit et al., 2017). In this regard, PCK studies in the literature mostly focus on the following two dimensions: Knowledge of student understanding and knowledge of instructional strategies and representations. Considering the tendency in literature, the following two dimensions were focused: (1) Knowledge of student understanding and (2) knowledge of instructional strategies and representations.

In the second phase, preliminary items were constructed (See APPENDIX C). The Turkish version of the preliminary items are presented in APPENDIX D. Throughout the item construction process, literature about students' understanding of heat and temperature was reviewed. Specifically, students' difficulties and misconceptions of heat and temperature, as well as instructional strategies that are used to overcome these challenges were identified. After developing the preliminary items, the first round of cognitive interviews was conducted with nine teachers. Five of the teachers were non-physics teachers including a middle school science teacher and a chemistry teacher. The remaining four teachers were physics teachers with various backgrounds. One physics teacher was a graduate of the physics education department of Boğaziçi University and has been working as a private school teacher

for five years. Another physics teacher was a graduate of the physics department of a university in İstanbul and had a teaching certificate. The teacher currently works as a paid teacher at a state school. Although she is a physics teacher, she currently works as a science teacher at a middle school. The remaining two physics teachers have been working at an old Anatolian high school for many years. Thus, these latter teachers were more experienced in terms of their years of work.

Cognitive interviewing is a method used to empirically study the way individuals perceive, process, and respond to instrument questions. Cognitive interviewing is generally conducted to pretest instrument questions and determine the modifications that are needed to make the questions more comprehensible (Lavrakas, 2008). In other words, cognitive validity of the items was also established by conducting cognitive interviews. Cognitive validity is defined as the interrelation between what an instrument item probes and what it really elicits from the respondents (Smith, 2017). In this way, it was examined whether the in-service physics teachers used the intended knowledge while answering the items. Furthermore, construct validity was also ensured by comparing the answers of physics teachers to the answers of teachers of different subjects. In the first round of cognitive interviews, teachers were given the test and they were requested to solve the questions as they were thinking aloud. Thus, their reasoning processes are tried to be illuminated. In this way, the similarities and differences in the response patterns between physics and non-physics were explored. In addition, the similarities and differences in response patterns within physics teachers were also investigated. Another reason to conduct cognitive interviews was to ensure that teachers utilize PCK of H&T as opposed to some other kind of knowledge while answering the questions. The inclusion of non-physics teachers in the interviews relies on the

assumption that non-physics teachers lack PCK of H&T and thus may not rely on PCK of H&T while solving the instrument items. In this way, it was ensured that the items could be solved by utilizing PCK of H&T rather than any other kind of knowledge. The first round of cognitive interviews lasted approximately 40 minutes. Both the first and second rounds of cognitive interviews were audio recorded and transcribed.

Most of the interviews were conducted online via the application of Zoom. The items were shown on the screen and teachers were allowed to use paper and pencil if they wanted to. The teachers were requested to solve the questions as they were thinking aloud. Teachers were requested to make further explanations whenever the interviewer felt that they did not display their reasoning processes. Thus, further explanations were requested especially when teachers were answering the multiple-choice questions. For example, when the teachers only said the name of an option as their response (A, B, C or D), questions such as “Why did you choose A?” were asked.

After evaluating the results of the first round of cognitive interviews and conducting an extended literature review, an item pool that consists of 53 items was developed (See APPENDIX E). The Turkish version of the comprehensive item pool is presented in APPENDIX F. In addition, a third dimension of PCK was also added to increase the comprehensiveness of the test. The table of specifications for each dimension of the comprehensive item pool is prepared (See APPENDIX G). Specifically, table of specifications for knowledge of student understanding is presented in Table G1, knowledge of instructional strategies is presented in Table G2, and knowledge of curriculum is presented in Table G3. The second round of cognitive interviews was conducted with ten teachers by using a comprehensive set

of items. Five of the participants were physics teachers, four of them work in a state school, and the other one works in a private school. Three of the participants were pre-service physics teachers who were senior students at a state university in İstanbul. The remaining two participants were non-physics teachers teaching religion and Turkish at state schools. One of these teachers is a paid teacher. The interviews lasted approximately two hours. However, still several of the teachers did not have the time to answer all the questions. In this regard, several items are distributed among the teachers. This approach is used in test development studies due to the efficiency it provides when there is a time constraint (Park et al., 2018).

Based on the results of the second round of cognitive interviews, several items that did not differentiate between the physics teachers and the non-physics teachers were revised or excluded from the test. For example, few non-physics teachers correctly answered several multiple-choice questions although they did not demonstrate the desired reasoning processes. Thus, these items were paired with an open-ended section that requires teachers to display their reasoning processes. In addition, Knowledge of Curriculum section was also excluded from the instrument. To check the content and construct validity of the instrument, a total of 33 items were sent to two physics education professors for their review. In this regard, an expert opinion form was developed (See APPENDIX H). Specifically, two physics education professors commented on whether the items were appropriate for the dimensions, whether the classification schema was sufficient for possible teacher responses, and whether the items were detailed enough to capture the intended knowledge dimensions. After an analysis of the physics education professors' reviews, nine more items were excluded from the test. Thus, a questionnaire that consists of 24 items were developed for the subsequent implementation of the test

(See APPENDIX I). The table of specifications for the final form of the written instrument is also developed (See APPENDIX J). Specifically, table of specifications for knowledge of student understanding is presented in Table J1 and knowledge of instructional strategies is presented in Table J2.

The PCK test was implemented to 90 physics teachers. The researcher first contacted the school principals and then directed to the teachers. The researcher first explained the aim of the research to the physics teachers and then asked whether they agreed to participate in the study. Teachers who agreed to participate in the study were given the questionnaires. Most of the time, teachers did not have enough time to fill out the questionnaire in the school. For this reason, the questionnaires were handed over to the teachers and then taken back in later days. The questionnaires were taken back when the teachers said they had completed the questionnaire. Over 120 questionnaires were handed over to physics teachers but 90 of them were received back. Teachers who didn't return the questionnaires said that they hadn't enough time to fill out the questionnaire, they withdrew from the study, or they lost the questionnaire. According to the teachers' statements, the time it takes to complete the scale varied between one to two hours.

3.3.3 Format of the test instrument and coding

Regarding the examination of teachers' PCK with a written instrument, the format of the items that assess PCK is of importance. The construction of instrument items is directly linked with the validity of a study and therefore should be carried out rigorously (Brovelli et al., 2014). In this regard, Brovelli et al. (2014) indicated that test items that intend to examine teachers' PCK should reflect the complexity of real classroom settings. The authors argued that only authentic test items such as

vignettes could appropriately elicit teachers' competencies. Vignettes are one type of item format and can be characterized as "contextualized description of classroom instruction" (Brovelli et al., 2014). Furthermore, they are defined as realistic scenarios of teaching and learning sequences (Kirschner et al., 2016). In this study, the items of the PCK test are constructed in a vignette format. The vignettes probed in-service physics teachers to demonstrate their PCK of heat and temperature. Vignettes were utilized as the main format of the items because they provide a realistic context for teachers to demonstrate their PCK (Hill et al., 2004). Furthermore, teachers may refrain from their knowledge being assessed, thus utilization of vignettes may decrease their unwillingness to answer the questions (Krauss et al., 2008; Hill et al., 2004).

During the vignette development process, literature about student understanding and instructional strategies was reviewed for the topic of heat and temperature. Existing instrument items that measure teachers' PCK of other topics were also scrutinized and several of them were adopted for the topic of heat and temperature. For example, Item 4, Item 5 and Item 11 of the Instructional Strategies section were adopted from an instrument that aims to examine pre-service biology teachers' PCK of biology. These items examine teachers' knowledge of the nature of true experiments. Moreover, several questions, strategies, or analogies used in the items were also adopted from existing studies. For example, Item 2 of the Knowledge of Student Understanding section presented a scenario in which a teacher asks his students a question (See APPENDIX E). The vignette further probed the physics teachers to come up with several wrong student answers. The question that the imaginary teacher asked his students in the vignette was adapted from the study of Güneş (2020). These questions were purposefully selected since they have been

previously validated. Several classification schemas were developed by consulting items of various instruments for several items. Table 16 presents items that were adopted from other studies. Items that depict adopted versions of questions, strategies, or analogies from different studies were also presented in the table.

Table 16. Items that were Adopted or Illustrate Examples from Existing Instruments

Item KSU.2	The example used in the item was adapted from the research study of Güneş (2020).
Item KSU.3	The example used in the item was adapted from the research study of Güneş (2020).
Item KSU.4	The example used in the item was adapted from the research study of Osberne and Cosgrove (1983).
Item KSU.5	The example used in the item was adapted from the research study of Güneş (2020).
Item KSU.6	The example used in the item was adapted from the research study of Shayer and Wylam (1981).
Item KSU.7	The example used in the item was adapted from the research study of Zacharia, Olympiou and Papaevripidou (2008).
Item KSU.10	The example used in the item was adapted from the research study of Lewis and Linn (1994).
Item KSU.12	The example used in the item was adapted from the research study of Güneş (2020).
Item IS.2b	The classification schema was adapted from the research study of Kirschner et al. (2016).
Item IS.4	The format of the item was adapted from the research study of Großschedl, Welter, and Harms (2019).
Item IS.5	The format of the item was adapted from the research study of Großschedl, Welter, and Harms (2019).
Item IS.6	The example used in the item was adopted from the web site: www.cookingforengineers.com/article/224/Heat-Transfer-and-Cooking/print
Item IS.10	The example used in the item was adapted from the research study of Schnittka and Bell (2010).
Item IS.11	The format of the item was adapted from the research study of Großschedl, Welter, and Harms (2019).
Item IS.12	The classification schema was adapted from the research study of Kirschner et al. (2016).

KSU: Knowledge of student understanding, KIS: Knowledge of instructional strategies

Both open-ended and closed-ended items were included in the instrument. Open-ended items may provide valuable information regarding the assessment of complex cognitive processes of individuals (Baxter & Lederman, 1999). Shulman (1987)

indicated that PCK entails a complicated form of reasoning before engaging in meaningful practice. Thus, PCK can be successfully utilized by teachers only if it is accompanied by action and reasoning. With this regard, constructing open-ended items that catch teachers' PCK and their underlying reasoning may provide better insight regarding the assessment purposes. However, well-designed closed-ended items permit assessing larger samples, decrease subjectivity in assessing subject responses, and enable asking more questions within a testing period (Walstad & Becker, 1994). Utilizing the advantages of both types of question formats, the written instrument consisted of a mixture of open-ended and closed-ended questions.

A classification schema was developed for each item (See APPENDIX K). The Turkish version of the items and classification schemas of the final instrument is presented in APPENDIX L. The classification schemas represent examples of teacher answers that are classified as correct, partially correct and false/irrelevant. The classification schemas were constructed by consulting literature and teacher answers obtained from the cognitive interviews. Furthermore, data analysis frameworks of Kellogg (2010) and Aliustaoğlu and Tuna (2019) were adopted for the classification schema of the PCK- H&T test. Answers to several items could be classified as either correct or false/irrelevant, whereas answers to remaining items were classified as correct, partially correct, or false/irrelevant. This differentiation in classification schemas stems from the nature of the items. For example, several items request physics teachers to infer alternative conceptions or student difficulties for a single sub-topic, whereas the remaining items request interpretation of alternative conceptions for more sub-topics. For items examining alternative conceptions of one sub-topic, responses were classified either as correct or false/Irrelevant.

However, the other items request the teachers to infer alternative conceptions or student difficulties of more than one sub-topic. In addition, teachers were also asked to not only infer the alternative conceptions but also engage in reasoning about the causes of student errors in some items. For these items, responses were classified either as correct, partially correct, or false/Irrelevant. This coding technique is commonly used in different PCK studies conducted in the field of science (Kirschner et al., 2016; Großschedl et al., 2019).

Ten percent of the open-ended items were coded by two raters independently. To enhance the reliability of scoring, the classification schema consisted of as many examples as possible for correct, incorrect, and partially correct answers, which are derived from literature and cognitive interviews.

The items of the test might have different scenarios. For example, teachers may be provided with a vignette and asked to select possible wrong student answers that students might give to a question. They may be additionally asked to engage in reasoning about why students may give incorrect answers or have difficulties and misconceptions. Furthermore, questions may require teachers to demonstrate their knowledge of instructional strategies. They might be expected to elaborate on the importance of addressing students' preconceptions in lessons, the advantages of using units etc. In this regard, the questions of the instrument probe teachers to engage in reasoning about their instructional choices.

3.3.4 Validity and reliability of the instrument

Several pieces of evidence were collected to establish the instrument's validity and reliability. Validity is defined as the "appropriateness of the interpretation" of an assessment method or tool (Miller et al., 2009). A variety of evidence could be

collected to establish the validity of an instrument. Content validity refers to "the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose" (Haynes, Richard, & Kubany, 1995, p. 238). In other words, content validity implies the degree of assessment items' representativeness of the domain that is targeted (Miller et al., 2009). In literature, expert examination of the assessment items is cited as an important way to ensure content validity (Carlson, 1990). In this regard, the content validity of the PCK test was ensured by consulting expert opinions. Specifically, the items were checked by two physics education professors throughout the phases of the instrument development process.

Construct validity refers to "the process of determining the extent to which performance on an assessment can be interpreted in terms of one or more constructs" (Miller et al., 2009, p.80). Discriminant validity is one type of construct validity which may be considered during the instrument validation process. Discriminant validity can be established by contrasting scores of different samples, which are expected to differ from each other. For example, Krauss et al. (2008), suggested comparing scores of teachers with scores of people from other professions. In this regard, Kirschner et al. (2016) compared physics and mathematics teachers' PCK scores and interpreted physics teachers' high-test scores as an indicator of discriminant validity. Thus, PCK scores of physics and non-physics teachers were compared to ensure that the instrument examines PCK of only physics teachers. In addition, PCK scores of in-service and pre-service physics teachers were compared to enhance the discriminant validity of the instrument. As Miller also et al. (2009) indicated, comparing scores of a target sample with other samples can be used as evidence for construct validation (p.83). Specifically, this comparison was made in

terms of the scores obtained from the cognitive interviews. It was assumed that the physics teachers draw more on PCK of H&T while solving the questions compared to non-physics teachers. In this way, the construct validity of the instrument was tried to be established. As Miller et al. (2009) indicated, "having participants think aloud" as they solve the items is one way of ensuring the construct validity of an instrument.

The procedures applied in the present study to establish the validity and reliability of the instrument were compatible with the procedures VASI and VNOS questionnaire development. These instruments are frequently used in science education field. During the development process of VASI and VNOS questionnaires, Lederman et al. (2002) collected a variety of evidence to ensure the validity of the questionnaires. The researchers conducted cognitive interviews to ensure the cognitive validity of the instruments. Furthermore, evidence for discriminant validity was also collected by comparing scores of different groups of participants, namely experts and novices. A similar approach was used in this study to ensure the validity of the instrument. Item analysis, Cronbach's alpha correlation, item-total correlation and inter-rater reliability analysis were conducted to investigate the reliability of the instrument.

3.4 Data analysis

In this study, data analysis was conducted in several steps. First, the cognitive interviews were analyzed to indicate whether the items could be solved with PCK of H&T or other kinds of knowledge. Specifically, responses of each teacher were classified as correct, false/irrelevant and/or partially correct. Comparisons were made

between physics teachers' scores and non-physics teachers' scores. Descriptive statistics were used during this process.

The paper and pencil questionnaire of PCK- H&T was analyzed with descriptive statistics. The analysis was conducted according to the pre-established classification schemas developed by the researcher. These codes were developed by consulting literature as well as the results of the first and second rounds of cognitive interviews.

The classification schema consists of labels such as correct, partially correct, false/irrelevant and blank. Items were classified as blank when the teachers did not provide any answer. Most of the teachers (n=71) completed the instrument and left very few items blank. However, 19 teachers did not complete the instrument. They left answering the items at various points of the instrument and did not respond to the upcoming items. These teachers generally filled out the first items and did not answer the following items in the instrument. Descriptive statistics of the rates of blank answers for each item were calculated and presented in the Results section.

Item statistics for the written instrument were also calculated. Specifically, item difficulty and item discrimination were analyzed. Item difficulty index is defined as the proportion of students who correctly answer an item (Miller et al., 2009). Item difficulty is commonly calculated to infer whether a test reliably measures the intended ability (Bachman, 1990). The values of item difficulty can range between 0 to 1. Values closer to 0 indicate more difficult items whereas values closer to 1 indicate easier items. Item difficulty is calculated for each item of a test. Values between .2 and .8 are regarded as acceptable as a rule of thumb.

Item discrimination is used to assess whether items can differentiate between high-ability and low-ability participants (Miller et al., 2009). The values of item

discrimination can range between -1 and 1. An item discrimination value of 1 indicates that the successful participants perform much better than the less successful participants. On the contrary, an item discrimination value of -1 indicates that the less successful participants perform much better than the successful participants. Item discrimination is calculated for each item of a test. Values greater than .2 are considered as acceptable in differentiating participants with different abilities.

Cronbach's alpha correlation and item-total correlation were also analyzed to investigate the internal consistency of the instrument. The intraclass correlation was conducted to investigate the inter-rater reliability of the instrument. In the literature, calculating inter-rater agreement for 10% of the participant responses was regarded as sufficient (Großschedl et al., 2019). In this regard, 10% of the responses to the instrument were independently coded by two different researchers.

3.5 Validity of the study

Throughout the study, threats to internal validity were also considered. Fraenkel et al. (2011) indicated that instrument decay is an internal validity threat for survey research designs. The instrument decay, an internal validity threat, implies a change in the nature of the instrument, including the scoring process. When the researchers score open-ended items and have to make interpretations, they might get exhausted in time. Thus, the scoring process might be influenced by the fatigue of the rater and result in invalid conclusions. The written instrument consists of multiple open-ended questions, and the threat of instrument decay is controlled by scheduling data scoring and developing a rubric.

CHAPTER 4

RESULTS

The aim of this study was to probe in-service physics teachers' PCK of heat and temperature by developing a written instrument. For this purpose, cognitive interviews were conducted, and a written instrument was developed and administered. First, two rounds of cognitive interviews were conducted with physics teachers and teachers of different subjects. Then, based on the results of the cognitive interviews, a written instrument was developed and administered to in-service physics teachers. The cognitive interviews were conducted to establish the construct validity of the instrument. In other words, whether the items intending to measure PCK are measuring PCK was examined. Informed by the results of the cognitive interviews and expert opinions, a paper and pencil test was developed and administered to in-service physics teachers. Both qualitative and quantitative analyses were conducted. First, the results of the qualitative analysis are presented. Then, the results of the quantitative analysis were elaborated.

4.1 Results of the qualitative analysis

In this section, the results of the two cognitive interviews and the results of the administration of the paper and pencil test were presented.

4.1.1 Results of the cognitive interviews

To establish the construct and cognitive validity of the items, two rounds of cognitive interviews were conducted. The interviews were conducted to examine whether the in-service physics teachers used the intended knowledge while answering the items.

Furthermore, evidence of construct validity was also gathered by comparing the answers of physics teachers to the answers of teachers of different subjects and preservice physics teachers.

First, preliminary 13 items were developed to probe the knowledge of student understanding and knowledge of instructional strategies components of PCK. Then, informed by the results of the first round of cognitive interviews, an item pool that consists of 53 items was developed and administered to eight teachers throughout the second round of cognitive interviews. The comprehensive item pool consisted of items that probe knowledge of student understanding, knowledge of instructional strategies, and knowledge of curriculum components of PCK. Below, the findings of the first round of cognitive interviews were presented.

4.1.1.1 Results of the first round of cognitive interviews

During the first round of cognitive interviews, the preliminary items were administered to physics teachers and teachers of different subjects (See APPENDIX C). Specifically, interviews with five non-physics and four physics teachers were conducted. First, teachers' answers to items that target to probe knowledge of student understanding dimension are presented. Then teachers' answers to items that target to probe knowledge of instructional strategies dimension are presented. Comparisons within the teacher groups are also made. In addition, differences between the performances of non-physics teachers and physics teachers are illustrated.

4.1.1.1.1 First round of cognitive interview results for the knowledge of student understanding dimension

The first round of cognitive interviews was conducted with five non-physics and four physics teachers. The teachers were requested to think aloud while solving the items. Scores of non-physics as well as physics teachers for each item of the knowledge of student understanding section are illustrated in Table 17.

Table 17. Scores of Non-Physics and Physics Teachers for Knowledge of Student Understanding Section

	Non-physics teachers					Physics teachers			
Item	CoT	RT	HT	ST	CT	PT1	PT2	PT3	PT4
KSU.1	0	0	0	0	1	1	0	1	0
KSU.2	1	1	0	1	1	1	1	1	1
KSU.3	0	0	0	0	0	1	0	0	0
KSU.4	0	0	0	1	1	1	1	0	1
KSU.5	0	0	0	0	0	2	0	0	1
KSU.6	0	0	0	0	0	1	0	0	0
KSU.7	0	0	0	0	0	1	1	1	1
Total	1	1	0	2	3	7	3	3	4

CoT: Counseling teacher, RT: Religion teacher, HT.: History teacher, ST.: Science teacher (middle school), PT1: Physics teacher 1, PT2: Physics teacher 2, PT3: Physics teacher 3, PT4: Physics teacher 4

The analysis of the answers of non-physics and physics teachers revealed several findings. Findings regarding the response patterns were as follows:

- One of the items was correctly answered by almost all the non-physics and physics teachers.
- A distribution among the performances of physics teachers was observed for the remaining items.

The most correctly answered item by most non-physics as well as physics teachers was Item 2 (See APPENDIX C). In this item, teachers are expected to state only two variables (mass and temperature) as an answer which can be easily

observed from the figure. During the interviews, all the physics teachers consulted their knowledge about calculating heat transfer. However, non-physics teachers had no idea about calculating the amount of heat transfer and still gave either temperature or mass as an answer. One reason for this high correct response rate might be the predictability of the answers. Since the non-physics teachers gave correct answers without demonstrating the intended knowledge and reasoning processes, the item is eliminated from the following phases.

For the remaining items, there was a distribution among the performances of the teachers. Specifically, counseling, religion, and history teachers (non-science teachers) performed considerably low compared to science, chemistry, and physics teachers. Non-science teachers could not give correct answers to open-ended questions. In almost all the cases, the non-science teachers could not identify the alternative conceptions. Moreover, they regarded almost all scientifically incorrect statements as correct. For example, all non-science teachers indicated that the reasoning process of the child in Item 3 seems plausible (See APPENDIX C). In this regard, they didn't provide coherent answers to the items. All the non-science teachers indicated that they don't have any idea about internal energy, specific heat, heat capacity and conditions of heat transfer. Thus, they got stuck when the questions required them to think about these concepts.

As expected, non-science teachers provided more answers to multiple-choice questions. Several multiple-choice questions allowed teachers to choose one or more than one option. Thus, there was a high probability for teachers to choose the correct answers. However, when non-science teachers are requested to make explanations, they provide faulty reasonings. For example, the counseling teacher correctly chose the "substances possess heat" option as an alternative conception in Item 5 (See

APPENDIX C). However, when she was requested to provide a reason, she said that "Not all the substances do have heat, for example, ice may not have any heat because it is cold". Her explanation reveals that although she chose one of the correct answers, she herself possesses the above-mentioned alternative conception.

The results of the analysis revealed that all the physics teachers stated that students have faulty thinking regarding heat and temperature concepts. Teachers gave several examples of alternative conceptions that they identified based on their own teaching experiences such as "Heat and temperature are the same". However, most of the physics teachers did not have a sound conceptualization of the alternative conception of "Substances possess heat". Item 3 requested teachers to identify the alternative conception of the student as "Substances possess heat" (See APPENDIX C). However, only one teacher could identify this alternative conception and made the following explanation: "Heat is something given or taken. Substances themselves do not possess heat". The remaining three teachers made explanations that reflect that they could not grasp the main problematic feature of the student thinking: "Students didn't consider the mass while they were calculating the heat of the objects", "Students ignored mass", "Students focused only on temperature". These statements highlight that the physics teachers could not correctly identify why the student made an incorrect comment. Even one physics teacher was found to possess the alternative conception. The teacher shared an example during the interview that she gives in her classes:

> I like to surprise students by giving interesting examples and make them to think. For example, I ask them whether a match or an ocean has more heat. They immediately say that a match has more heat. Then I tell them that the ocean has more heat, and they get surprised. In this way, they learn that they have to consider mass while calculating heat of the objects.

As can be seen from the teacher's explanation, the teacher possesses a scientifically incorrect conception of heat.

Findings regarding teachers' conceptions of internal energy are also worth focusing on. All the physics teachers correctly identified pre-knowledge that students should possess before learning internal energy. This implies that teachers have a grasp of the textbook definition of internal energy. However, teachers' answers to Item 5 revealed that they have a deficient conception of internal energy (See APPENDIX C). For example, two physics teachers labeled the alternative conception "Internal energy is the total amount of heat that a substance possesses" as scientifically correct. One teacher stated that this is the definition of internal energy that they give in classes. However, the statement is scientifically incorrect. The same teacher indicated that there are fluctuations in terms of the content of the internal energy that are given in the curriculum and MoNE textbooks year by year. She also added that internal energy is not presented properly and in detail in the textbooks. The responses of the physics teachers revealed that there are problematic issues regarding their conceptualization of internal energy.

Science and chemistry teachers outperformed non-science teachers on the test. Importantly, they did not get stuck while solving open-ended questions and provided more coherent explanations. However, they still could not identify most of the alternative conceptions and their statements imply that they themselves possess alternative conceptions such as substances possess heat. The chemistry teacher indicated that concepts such as specific heat and heat capacity are not present in the chemistry curriculum, and she does not remember these concepts from her undergraduate years. In this regard, she could not provide any answer to the questions that included concepts such as specific heat and heat capacity. She

outperformed non-science teachers with her performance on the 1st question which requires an examination of a change of state graph. This finding may imply that a PCK test that measures physics teachers' knowledge should not heavily target concepts related to change of state. In a similar vein, the science teacher herself possessed alternative conceptions such as "Substances possess heat". Moreover, she could not correctly identify several scientifically correct and incorrect conceptions especially about internal energy.

4.1.1.1.2 First round of cognitive interview results for the knowledge of instructional strategies dimension

Scores of non-physics as well as physics teachers for each item of knowledge of instructional strategies section are illustrated in Table 18.

Table 18. Scores of Non-Physics and Physics Teachers for Knowledge of Instructional Strategies Section

	Non-physics teachers					Physics teachers			
	CoT	RT	HT	ST	CT	PT1	PT2	PT3	PT4
KIS.1	1	1	0	1	1	1	1	1	1
KIS.2	0	0	0	0	0	1	0	1	1
KIS.3	0	0	0	0	0	1	0	0	0
KIS.4	0	0	0	0	0	1	0	0	0
KIS.5	0	0	0	0	0	1	0	1	1
KIS.6	0	0	0	0	0	0	0	1	0
Total	1	1	0	1	1	5	1	4	3

Counseling teacher, RT: Religion teacher, HT.: History teacher, ST.: Science teacher (middle school), PT1: Physics teacher 1, PT2: Physics teacher 2, PT3: Physics teacher 3, PT4: Physics teacher 4

The most correctly answered item was Item 1 (See APPENDIX C). Four of the non-physics teachers correctly answered Item 1. This was also the item which all the physics teachers correctly answered. The item requested teachers to choose the best

material list for conducting an experiment. There could be several reasons why most of the non-physics teachers correctly answered Item 1. The item may elicit the knowledge of the experiment with a shallow reference to physics content. Thus, the item may target general pedagogical knowledge and could be solved by thinking logically rather than consulting PCK.

Physics teachers' answers to analogy questions also revealed interesting notions. Item 3 and Item 4 requested teachers to think conceptually about several concepts such as temperature and heat capacity (See APPENDIX C). Teachers were expected to think about temperature on the molecular level (Item 3). Similarly, teachers were expected to conceptually think about heat capacity in the sandbag example (Item 4). However, only PT 1 correctly answered the analogy questions that elicit conceptual thinking. The remaining teachers did not provide detailed explanations. Most of the teachers also did not use specific terms such as convection and radiation when they were requested to identify ways of heat transfer in Item 2 (See APPENDIX C). Only PT 1 correctly identified convection and none of the teachers identified radiation. This may also stem from the lack of clarity of the figure used in the question. More explicit visuals can be used in subsequent iterations to capture teachers' knowledge more validly.

A summary of the findings regarding the first round of cognitive interviews is presented below:

- Two of the items were correctly answered by almost all the non-physics and physics teachers. Thus, no distinct distribution among teachers' performance was observed for these questions. For Item 2 of the Knowledge of Student Understanding section, the reason for this might be the easy predictableness of the answers. For Item 1 of the Knowledge of Instructional Strategies

section, the question might measure knowledge of general experimenting skills rather than knowledge about instruction of physics. This result may imply several problems about the validity of the two questions. It was concluded that these questions should be revised or eliminated from a test that targets to measure physics teachers' PCK.

- For the remaining 11 questions, there was a clear distribution among the performances of the teachers. Specifically, non-science teachers demonstrated the lowest performance compared to science, chemistry, and physics teachers.
- Non-science teachers provided no clear response when they were solving the open-ended questions. They provided several responses to several multiple-choice questions. However, most of the reasoning they provided for their choices was scientifically incorrect.
- Non-science teachers indicated that they have no idea about internal energy, specific heat, and heat capacity. Thus, they couldn't provide any coherent answer to questions that include these terms.
- Although the science teacher and the chemistry teacher outperformed the non-science teachers, they also couldn't identify several alternative conceptions regarding heat and internal energy. Their performance was low compared to physics teachers.
- The chemistry teacher herself indicated that terms such as specific heat and heat capacity are not present in the chemistry curriculum. In this regard, she expressed that she doesn't remember these terms. As a result, she couldn't provide any coherent answer to questions that include these terms.
- The chemistry teacher outperformed the counseling, religion, and history teachers on Item 1 of Knowledge of Student Understanding section. Item 1 is

about the change of state. It may be concluded that a PCK test that targets physics teachers' PCK should not heavily rely on the change of state concept.

- All the non-physics teachers gave incorrect answers to analogy questions that requested them to think conceptually.
- Internal energy was the most problematic topic in terms of the physics teachers' conceptualizations. Only, PT 1 correctly identified all the (given) scientifically correct and incorrect conceptions of internal energy. The remaining physics teachers regarded several scientifically correct conceptions of internal energy as scientifically incorrect. Similarly, they regarded several scientifically incorrect conceptions as scientifically correct. This implies that they either do not coherently know internal energy or they themselves possess alternative conceptions of internal energy.
- Most of the physics teachers could not infer the alternative conception of "Substances possess heat". Even one physics teacher was found to possess this alternative conception.
- Most of the physics teachers (n=3) couldn't solve the analogy questions that require them to think conceptually about temperature and heat capacity (Item 3 and Item 4 of Knowledge of Instructional Strategies section). Only PT 1 provided correct answers to these questions.
- Most of the physics teachers did not use terms such as convection and radiation when they were requested to define ways of heat transfer. Only PT 1 used the term convection. None of the teachers used the term radiation. This may stem from the lack of clarity of the figure presented to teachers in the question (Item 2 of Knowledge of Instructional Strategies section). This

finding implies that figures should be designed more clearly before being used in a PCK test.

4.1.1.2 Results of the second round of cognitive interviews

During the second round of cognitive interviews, the comprehensive item pool is administered to non-physics, physics, and pre-service physics teachers (See APPENDIX E). The interviews lasted approximately two hours. First, teachers' answers to items that target to probe knowledge of student understanding are presented. Then, teachers' answers to items that target to probe knowledge of instructional strategies are presented. Finally, teachers' answers to items that target to probe knowledge of curriculum are illustrated. Comparisons within the teacher groups were also made. In addition, differences between the performances of non-physics, physics, and pre-service physics teachers are illustrated.

4.1.1.2.1 Cognitive interview results for the knowledge of student understanding dimension

The items of the Knowledge of Student Understanding dimension of the item pool were administered to all the teachers except one pre-service physics teacher. The PST3 responded to only four items due to time restrictions. The scores of each teacher are presented in Table 19. The results suggest that non-physics teachers obtained the lowest scores on the test. Pre-service physics teachers and physics teachers obtained higher scores compared to non-physics teachers.

Table 19. Scores of Teachers for Knowledge of Student Understanding Dimension

	Non-physics teachers		Pre-service physics teachers			Physics teachers		
Item	TT	RT	PST1	PST2	PST3	PT1	PT2	PT3
KSU.1	0	0	0	0	-	0	0	0
KSU.2	0	0	0	0	-	0	0	0
KSU.3	0	0	0	0	-	0	0	0
KSU.4	0	0	0	1	-	0	1	1
KSU.5	0	0	0	0	-	0	1	0
KSU.6	0	0	0	0	-	0	1	1
KSU.7	0	0	0	1	-	0	1	1
KSU.8	0	0	0	1	-	1	0	1
KSU.9	0	0	0	0	-	0	0	0
KSU.10	0	0	1	1	-	0	1	1
KSU.11	0	0	0	0	1	0	0	1
KSU.12	0	0	0	0	0	0	0	1
KSU.13	0	0	0	0	0	0	1	1
KSU.14	0	0	1	0	1	0	0	0
KSU.15	0	0	1	0	-	1	1	1
KSU.16	0	0	0	1	-	1	1	1
KSU.17	0	0	1	0	-	0	1	1
KSU.18	0	0	0	1	-	0	0	1
KSU.19	0	0	0	0	-	0	1	1
KSU.20	0	1	0	0	-	1	1	1
KSU.21	0	0	0	0	-	0	0	0
KSU.22	0	0	0	1	-	0	1	0
Total	0	1	4	7	2/4	5	12	14

TT: Turkish teacher, RT: Religion teacher, PST1: Pre-service physics teacher 1, PST2: Pre-service physics teacher 2, PST3: Pre-service physics teacher 3, PT1: Physics teacher 1, PT2: Physics teacher 2, PT3: Physics teacher 3

There was a distribution among the scores of the physics teachers. However, several items of this section could not be answered by any physics teacher whereas several items were answered by all the physics teachers. For example, all the physics teachers got a score of zero from the Items 1, 2, 3, 9, 14 and 21. On the contrary, Items 15, 16 and 20 were correctly answered by all physics teachers. This result suggests that these items should be scrutinized in line with the feedback obtained from the experts. In other words, since there is no distribution among the scores of physics teachers, these items may be strong candidates to be excluded from the test.

The results of the first round of cognitive interviews suggested that relying only on answers to multiple-choice questions may not be sufficient to fully capture teachers' PCK. For this reason, most multiple-choice questions are paired with an open-ended question in the second round of cognitive interviews to better illuminate the reasoning processes of the teachers. The benefits of this approach can be traced in the answer of the Turkish teacher to Item 3. The Turkish teacher chose the correct options for the multiple-choice section. However, the teacher indicated that "I would choose the second and third options. I don't know whether they are correct or wrong. But I think that my reasoning process is like a student who thinks wrong". In this regard, the teacher didn't get any points because he didn't give a correct answer to the open-ended part of the item although he chose the correct options.

One problematic item in this section was Item 21. The item requested teachers to come up with an alternative conception that may be caused by a demonstration. The demonstration aimed to illustrate heat equilibrium by associating the liquid with heat. The association of heat with something liquid may cause the alternative conception of "Heat is a matter such as liquid". None of the physics teachers demonstrated the intended reasoning while solving the item. Most of the physics teachers could not provide any relevant explanation and got stuck.

4.1.1.2.2 Cognitive interview results for the knowledge of instructional strategies dimension

The items of the knowledge of instructional strategies dimension of the PCK- H&T test were administered to all the teachers. Only one pre-service physics teacher (PST2) answered several of the items. The scores of each teacher are presented in Table 20. The results suggest that non-physics teachers obtained the lowest scores on

the test. Pre-service physics teachers and physics teachers obtained higher scores compared to non-physics teachers. It can be also said that physics teachers' scores are generally higher than those of pre-service physics teachers.

Table 20. Scores of Teachers for Knowledge of Instructional Strategies Dimension

	Non-physics teachers		Pre-service physics teachers			Physics teachers		
Item	TT	RT	PST1	PST2	PST3	PT1	PT2	PT3
KIS.1	0	0	0	1	1	0	1	1
KIS.2	0	0	1	0	0	0	1	1
KIS.3	0	0	0	1	0	0	1	1
KIS.4	0	0	0	0	1	0	1	0
KIS.5	0	0	0	0	1	0	1	1
KIS.6	0	0	0	0	1	0	0	0
KIS.7	0	0	0	0	0	0	0	0
KIS.8	0	0	0	-	0	0	0	0
KIS.9	0	0	0	-	0	0	1	1
KIS.10	0	0	1	-	1	1	1	1
KIS.11	0	0	0	-	0	0	1	1
KIS.12	0	0	0	0	0	0	1	1
KIS.13	1	1	1	-	1	1	0	1
KIS.14	0	0	0	-	0	0	1	1
KIS.15	0	0	1	1	1	1	1	2
KIS.16	0	0	0	-	0	0	0	0
KIS.17	0	0	0	-	0	0	0	0
KIS.18	0	0	0	0	0	1	0	1
KIS.19	0	0	0	0	0	0	1	0
KIS.20	0	0	0	-	0	0	0	1
Total	1	1	4	3/12	7	4	11	14

Turkish teacher, RT: Religion teacher, PST1: Pre-service physics teacher 1, PST2: Pre-service physics teacher 2, PST3: Pre-service physics teacher 3, PT1: Physics teacher 1, PT2: Physics teacher 2, PT3: Physics teacher 3

There was distribution among the scores of the physics teachers. However, several items of this section could not be answered by any physics teacher whereas several items were answered by all the physics teachers. For example, all the physics teachers got a score of zero from Items 7, 8 and 16 and 17. On the contrary, Item 10 was correctly answered by all physics teachers and Item 13 was correctly answered by all non-physics teachers. This result suggests that these items should be scrutinized in line with the feedbacks obtained from the experts. In other words,

since there was no distribution among the scores of the physics teachers, these items may be strong candidates to be excluded from the test.

One problematic item in this section was Item 13. Almost all different groups of teachers gave a correct answer to this item. The teachers were asked to identify an activity in terms of the steps of experimentation. All the non-physics teachers identified the activity as observation.

4.1.1.2.3 Cognitive interview results for the knowledge of curriculum dimension

The items of the knowledge of curriculum dimension of the PCK- H&T test were administered to most of the teachers. Only two pre-service physics teachers could not answer the section due to time restrictions. The scores of each teacher are presented in Table 21. The results suggest that non-physics teachers obtained the lowest scores on the test. Pre-service physics teachers and physics teachers obtained higher scores compared to non-physics teachers. It can be also said that physics teachers' scores are generally higher than those of pre-service physics teachers. Only one physics teacher's (PT1) score is lower than a pre-service physics teacher (PST3).

The results suggest that physics teachers' scores had a distribution only for four out of the eleven items. For the remaining items, all the physics teachers gave either correct or incorrect answers. Since there was no distribution among the scores of physics teachers for most of the items, this section was excluded from the instrument. In addition, there was also no balanced distribution in terms of the types of the items. The majority of the items were multiple-choice.

Table 21. Scores of Teachers for Knowledge of Curriculum Dimension

	Non- physics teachers		Pre-service physics teachers			Physics teachers		
	TT	RT	PST1	PST2	PST3	PT1	PT2	PT3
KC.1	0	0	-	-	0	1	1	1
KC.2	0	0	-	-	0	0	0	0
KC.3	0	0	-	-	0	0	0	0
KC.4	0	0	-	-	0	0	0	0
KC.5	0	0	-	-	1	1	1	1
KC.6	0	0	-	-	0	0	1	1
KC.7	0	0	-	-	1	0	1	1
KC.8	0	0	-	-	1	0	0	0
KC.9	0	0	-	-	0	0	0	1
KC.10	0	0	-	-	0	0	0	0
KC.11	0	0	-	-	1	0	1	1
Total	0	0	-	-	4	2	5	6

Turkish teacher, RT: Religion teacher, PST1: Pre-service physics teacher 1, PST2: Pre-service physics teacher 2, PST3: Pre-service physics teacher 3, PT1: Physics teacher 1, PT2: Physics teacher 2, PT3: Physics teacher 3

The cognitive interviews were conducted with physics, non-physics, and pre-service physics teachers for the purpose of investigating their response patterns. A summary of the findings regarding the second round of cognitive interviews is presented below:

- Physics teachers and pre-service physics teachers obtained higher scores than non-physics teachers. Physics teachers generally obtained higher scores than pre-service physics teachers.
- There was a distribution among the scores of the physics teachers. However, several of the items were correctly answered or could not be answered by all the physics teachers. These items were strong candidates to be eliminated from the test.
- The results for knowledge of curriculum section illustrated no distribution for most of the items among physics teachers. Thus, this section was excluded from the instrument.

- By considering expert opinions and cognitive interview results, several items were excluded from the item pool. These items either did not differentiate physics teachers from preservice physics teachers or among themselves. Items that did not lead the physics teachers to use the intended knowledge and reasoning as well as not understood by them were also excluded. 10 items were excluded from the Knowledge of Understanding section and 8 items were removed from the Knowledge of Instructional Strategies section.
- Item 1, Item 2, Item 3, Item 9, Item 10, Item 14, Item 16, Item 20, Item 21, and Item 22 were excluded from the Knowledge of Student Understanding section, and Item 6, Item 7, Item 8, Item 10, Item 13, Item 16, Item 17 and Item 20 were excluded from the Knowledge of Instructional Strategies section.

4.1.2 Results of the implementation of the PCK- H&T test

After the analysis of the second round of cognitive interviews and expert reviews, a paper and pencil test consisting of 24 items was developed. Items and classification schemas are presented in APPENDIX K. The test was administered to 90 in-service physics teachers. According to the statements of the physics teachers, the duration of the test lasted between one to two hours. Descriptive statistics were used to analyze the data.

4.1.2.1 Overview of the results of the implementation of the PCK- H&T test

In this section, an overview of the results of the Knowledge of Student Understanding and Knowledge of Instructional Strategies sections are presented. First, the results of the Knowledge of Student Understanding section are presented.

This section consists of 12 items that probe physics teachers' knowledge of student understanding. The items of the test were developed in vignette form. The section consists of both open-ended and closed-ended items. Teachers' answers to several items were classified as correct, partially correct or false/irrelevant whereas answers to remaining items were classified as correct or false/irrelevant. The results of the analysis of answers to Item 1, Item 10 and Item 12 are presented in Table 22.

Table 22. Analysis of the Answers to Item1, Item 10 and Item 12 of the Knowledge of Student Understanding Section

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n(%)
KSU.1	13 (14%)	30 (33%)	57 (53%)	0 (0%)	90 (100%)
KSU.10	14 (16%)	32 (36%)	38 (42%)	5 (5%)	90 (100%)
KSU.12	33 (37%)	39 (43%)	13 (14%)	5 (5%)	90 (100%)

The results of the analysis of the remaining items (Item 2, Item 3, Item 4, Item 5, Item 6, Item 7, Item 8, Item 9, and Item 11) are presented in Table 23.

Table 23. Analysis of the Answers to Remaining Items of the Knowledge of Student Understanding Section

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.2	67 (74%)	21 (23%)	2 (2%)	90 (100%)
KSU.3	76 (84%)	13 (14%)	1 (1%)	90 (100%)
KSU.4	51 (56%)	29 (32%)	10 (11%)	90 (100%)
KSU.5	32 (36%)	54 (60%)	4 (4%)	90 (100%)
KSU.6	38 (42%)	45 (50%)	7 (8%)	90 (100%)
KSU.7	85 (95%)	3 (3%)	2 (2%)	90 (100%)
KSU.8	70 (78%)	14 (16%)	6 (7%)	90 (100%)
KSU.9	25 (28%)	61 (68%)	4 (4%)	90 (100%)
KSU.11	71 (79%)	14 (16%)	5 (5%)	90 (100%)

The results of the analysis of the paper and pencil questionnaire revealed different findings regarding the physics teachers' knowledge of student understanding. These findings can be summarized as follows:

- The physics teachers demonstrated different levels of knowledge regarding different alternative conceptions of students. Many of the physics teachers demonstrated a high performance regarding students' understanding of temperature. A high number of physics teachers correctly inferred the alternative conceptions "Temperature can be transferred" and "There are multiples of temperatures in degrees Celsius".
- Regarding the alternative conceptions of heat, nearly half of the teachers could not interpret the alternative conception "Substances possess heat". Although they could detect the problematic statements of students, they made less informed interpretations.
- Most of the physics teachers correctly interpreted student understanding of heat transfer (Item 8). However, more than half of the physics teachers could not interpret another alternative conception of heat: "When the same amount of heat is given to different substances, their final temperatures will be the same."
- A high number of teachers made correct interpretations of student understanding of the basic internal energy definition (Item11). However, 27% of the physics teachers could not correctly solve a complex question about internal energy (first section of Item 5). They regarded the scientifically correct answer as incorrect. This result may give clues about the physics teachers' content knowledge levels of internal energy. In addition, most of the

physics teachers did not infer the alternative conception of internal energy in Item 1.

- The physics teachers demonstrated the lowest performance in students' understanding of heat conduction. More than half of the physics teachers' answers to items about heat conduction were classified as false/irrelevant.

The overview of the results of the Knowledge of Instructional Strategies section is presented below. This section consists of 12 items that measure physics teachers' knowledge of instructional strategies. The section consists of both open-ended and closed-ended items. The results of the analysis of Item 3, Item 8, Item 9, and Item 11 are presented in Table 24.

Table 24. Analysis of the Answers to Item 3, Item 8, Item 9 and Item 11 of the Knowledge of Instructional Strategies Section

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
KIS.3	43 (48%)	34 (38%)	5 (6%)	8 (9%)	90 (100%)
KIS.8	9 (10%)	50 (56%)	23 (26%)	10 (9%)	90 (100%)
KIS.9	21 (23%)	18 (20%)	40 (45%)	11 (12%)	90 (100%)
KIS.11	9 (11%)	34 (37%)	28 (31%)	19 (21%)	90 (100%)

The results of the analysis of the remaining items (Item 1, Item 2, Item 3, Item 4, Item 5, Item 6, Item 7, and Item 12) are presented in Table 25.

Table 25. Analysis of the Answers to Remaining Items of the Knowledge of Instructional Strategies Section

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.1a	74 (82%)	5 (6%)	11 (12%)	90 (100%)
KIS.1b	43 (%48)	33 (%37)	14 (%16)	90 (100%)
KIS.2a	41 (%46)	39 (%43)	10 (%11)	90 (100%)
KIS.2b	16 (%18)	50 (%56)	24 (%27)	90 (100%)
KIS.4	45 (50%)	35 (39%)	10 (11%)	90 (100%)
KIS.5	19 (21%)	48 (53%)	23 (26%)	90 (100%)
KIS.6	26 (29%)	48 (53%)	16 (21%)	90 (100%)
KIS.7	43 (48%)	37 (41%)	10 (11%)	90 (100%)
KIS.12	56 (62%)	24 (27%)	10 (11%)	90 (100%)

The results of the analysis of the paper and pencil questionnaire revealed different findings regarding the physics teachers' knowledge of instructional strategies. These findings can be summarized as follows:

- Most of the physics teachers successfully designed experiments to correct false student ideas. However, they demonstrated a comparatively low performance when they were expected to express the importance of considering student conceptions while designing lessons. This might be explained by the structure of traditional classrooms. Generally, teachers tend to immediately correct false student responses rather than delve deeper into students' understandings.
- The physics teachers' performance in the use of analogies was low. More than half of the physics teachers could not correctly answer items that aim to assess their knowledge of analogies about temperature, heat conduction and heat capacity.
- More than half of the physics teachers could not correctly differentiate science activities from true experiments. Although half of the physics teachers could correctly identify the mistake of a student who aims to design

a controlled experiment, half of the physics teachers made less informed interpretations regarding the nature of the controlled experiments.

- The physics teachers demonstrated the highest performance on items that assess the advantages of using the units while making calculations and using simulations while conducting experiments.
- Nearly half of the physics teachers gave informed answers to items about demonstrations. However, the remaining teachers could not make informed interpretations.

4.1.2.2 Results of the knowledge of student understanding section of the PCK- H&T test

In this section, the results of the Knowledge of student understanding section of the PCK-H&T test are presented item by item.

Item 1 presents physics teachers with a scenario in which a student makes an interpretation of a temperature-time graph. The imaginary student's interpretation reflects three alternative conceptions of heat, temperature, and internal energy concepts. The physics teachers are expected to infer all these alternative conceptions. Based on the results of the second round of cognitive interviews, a coding schema was developed that classifies teachers' responses as correct, partially correct, and false/irrelevant. Responses of the physics teachers who correctly inferred all three alternative conceptions were classified as correct. In a similar vein, responses of the physics teachers who correctly inferred one or two alternative conceptions were classified as partially correct. Finally, responses of teachers who could not infer any alternative conception or were irrelevant were classified as false/irrelevant. Table 26 demonstrates the number of teacher responses that belong to each category.

Table 26. Descriptive Statistics of Teacher Responses to Item 1

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
SU.1	13 (14%)	72 (80%)	5 (6%)	0 (0%)	90 (100%)

As it can be seen from the table, only 14% of the physics teachers could infer all three alternative conceptions of the students. For example, PT 2's interpretation sufficiently reflects the following alternative conceptions: (1) Substances have heat. (2) Internal energy is a measure of the total heat of a substance. (3) Temperature can be transmitted. His response that is classified as correct is as follows:

> There cannot be the heat of an object. The temperature of the objects K and L are wrong sentences. The truth is that the objects K and L should have temperatures. His interpretation of the internal energy from heat was wrong. He could have said it because the temperature of K was high. Of course, the internal energy is not a concept that depends only on temperature. (It is related to kinetic + potential energy). The temperature transition from K to L is a wrong sentence, he should have said the heat transition from K to L.

Almost all the physics teachers' answers were classified as partially correct (80%). For example, PT 18 mentioned the erroneous student statement about substances' heat and temperature flow and referred in total two alternative conceptions (See Table 27). Different from PT 18, PT 10 also mentioned the alternative conception of internal energy. Indeed, a very small number of teachers (n=20) made relevant interpretations about internal energy. The answer of PT 56 was also classified as partially correct since he mentioned the alternative conception of heat.

Table 27. Examples of Teacher Responses to Item 1 Classified as Partially Correct

	Teacher responses
PT 18	"Comparing heat between objects. Claiming that object K has more heat. Thinking of the energy transferred between objects as a temperature transfer."
PT 10	"A substance cannot have heat. Heat is the energy transferred due to a temperature difference. Since something cannot have heat, it cannot be compared with internal energy. She should have said that since its temperature is high, its internal energy is high."
PT 56	"Since heat is transferred energy, it is not possible to talk about the heat of an object or system. The student has not grasped the relationship between the concept of temperature and heat."

A typical teacher answer to item 1 was "Students confused heat and temperature" (n=17). One might argue that the idea of heat as something possessable and temperature as something flows result in this confusion. This answer is also classified as partially correct since it reflects some characteristics of the two alternative conceptions. However, since no precise interpretations of the alternative conceptions were made, this answer can be considered less sophisticated.

Two physics teachers' answers to Item 1 might convey different findings. When the answer of PT 15 was analyzed, it can be said the teacher himself might possess the alternative conception of "Substances possess heat". This might be inferred from his quote: "…The student should have said that the heat of K decreased, and the heat of L increased…". Although PT 15 correctly identified the misconception of "Temperature can be transmitted", he fails to interpret students' alternative conception of heat, and this may be attributed to his own alternative conception. As indicated in the literature, teachers' content knowledge and pedagogical content knowledge are two related constructs and lower levels of content knowledge might imply lower levels of pedagogical content knowledge. Thus,

specifically for this situation, the lower levels of knowledge of student understanding might be attributed to lower levels of content knowledge.

Like PT 15, PT 13 used phrases that might imply that she also has the alternative conception of "Substances possess heat". She said that "…It cannot be said that K's heat is higher…" which might sound scientifically correct. However, she continued with "The types of substances, that is, their specific heats, are not known, so we cannot compare their heat". She herself uses the expression of heat of substances and this gives clues about her own understanding of heat.

Item 2 presented a scenario and requested the physics teachers to infer possible incorrect student answers that reflect alternative conceptions. A high number of teachers (%74) could come up with student answers that reflect alternative conceptions (See Table 28). However, 21% of the teachers could not state any meaningful student answer that is scientifically incorrect.

Table 28. Descriptive Statistics of Teacher Responses to Item 2

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.2	67 (74%)	21 (23%)	2 (2%)	90 (100%)

The most frequently stated alternative conception was "The metal one is colder" or "The wood one is hotter". For example, PT 52 correctly made the following interpretation: "Although wooden and metal-handled brooms were in the same environment, the metal-handled broom was said to be colder".

Physics teachers inferred three alternative conceptions in total. The alternative conceptions that are stated by teachers are depicted in Table 29.

Table 29. Alternative Conceptions that are Stated by Teachers in Item 2

Alternative conceptions	n	%
The metal one is colder/The wood one is hotter.	62	69
Metal and wood have different specific heats.	9	10
Coldness passes from metal to Ahmet. / Metal conducts cold better.	6	7

Examples of teachers' answers that are classified as false/irrelevant are depicted in Table 30. PT 39 mentioned no possible wrong student answers but just merely repeated that students could have misunderstood heat, temperature, felt temperature, heat transfer, heat equilibrium, etc. Similarly, PT 51 indicated that students do not consider heat conduction and heat conduction coefficient and use alternative conceptions.

Table 30. Examples of Teacher Responses to Item 2 Classified as False/Irrelevant

	Teacher responses
PT 39	"He may have misunderstood the concept of heat, the concept of temperature, the concept of perceived temperature."
PT 51	"When answering these questions, the student acts with incorrectly known truths without considering heat conduction and heat conduction coefficient."

Item 3 is correctly answered by most of the physics teachers. 84% of the teachers inferred the alternative conception that is present in the problem scenario (See Table 31).

Table 31. Descriptive Statistics of Teacher Responses to Item 3

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.3	76 (84%)	13 (14%)	1 (1%)	90 (100%)

For example, PT 42 correctly specified the erroneous statement of the student as follows: “When interpreting the graph, he uses the wrong expression, 2 times °C. In order to say that… he should have used the K degree”. The physics teacher also added the condition in which one could double the temperature units.

A teacher answer to Item 3 classified as false/irrelevant is as follows: “It depends not only on the heat it receives over time but also on the mass”. PT55 did not focus on the main problematic statement of the student but rather emphasized an irrelevant detail. Although the teacher’s comment reveals a fact about heat and temperature, the student in the scenario did not make any false interpretations but rather focused only on the relation between heat and temperature. This does not imply that the student missed the relation between mass and temperature change.

The fourth item requested the physics teachers to come up with common incorrect student statements about condensation. Teachers are asked what answers students could give to a compelling question about condensation. The results of the analysis revealed that 56% of the physics teachers came up with a common student statement that can be labeled as scientifically incorrect (See Table 32). However, 32% of the physics teachers could not indicate any meaningful student statement or gave irrelevant answers. 11% of the physics teachers left the question blank.

Table 32. Descriptive Statistics of Teacher Responses to Item 4

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.4	51 (56%)	29 (32%)	10 (11%)	90 (100%)

The most frequently cited alternative conceptions were “There has been evaporation” (n=19) and “The ice melted, overflowed and wetted the surface of the jar” (n=13).

Other three alternative conceptions that are inferred by the teachers were “The jar is sweating” (n=10), “Water leaked out because there were small gaps in the jar” (n=6) and “The jar gave off heat to the outside” (n=5).

Most of the teachers who gave correct answers found only one student alternative conception. Only three teachers came up with more than one alternative conception. For example, PT 63 correctly interpreted two alternative conceptions as follows: “Water has leaked out of the jar. The water has evaporated, so the outside of the jar is wet.”

Examples of teacher responses that are classified as false/irrelevant are depicted in Table 33. The answer of PT 56 is classified as false/irrelevant since his statement does not reflect any relevant erroneous way of student thinking. PT 17 did not mention any possible student answer but simply stated the scientifically correct explanations. Thus, her answer is classified as false/irrelevant. In a different vein, PT 59 simply stated that students could not understand where the water around the glass comes from. All these answers do not provide meaningful explanations regarding students’ points of view about condensation.

Table 33. Examples of Teacher Responses to Item 4 Classified as False/Irrelevant

	Teacher responses
PT 56	“The wrong answer that the student can give is that the jar steams up because the temperature outside is different and the temperature inside is different.”
PT 17	“The conversion of a gaseous substance into a liquid. It is the opposite of evaporation.”
PT 59	“They can't understand where the water outside the glass comes from.”

The fifth item asks teachers to select incorrect answers that students might give to a multiple-choice question. Teachers are also requested to infer students’ alternative conceptions that might lead them to select the incorrect choices. 69% of the physics

teachers correctly selected incorrect student answers (See Table 34). However, only 36% of the teachers could infer the alternative conceptions that might lead students to select wrong choices. The remaining teachers could not indicate any meaningful erroneous thoughts of students.

Table 34. Descriptive Statistics of Teacher Responses to Item 5

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.5	32 (36%)	54 (60%)	4 (4%)	90 (100%)

PT 4 indicated that "The juice and soda eventually reach the same internal energy. The juice and soda eventually reach the same temperature". PT4 correctly selected the incorrect answers that a student might give to the multiple-choice question but did not make any sophisticated explanation regarding the alternative conceptions of students. The teacher just repeated the false judgments that a student might make but did not provide any erroneous thinking examples that result in these judgments.

PT 70 made another false/irrelevant interpretation as follows: "They have not fully learned the concepts of heat and temperature. The difference between whether enough time has passed or not becomes a problem". The teacher again correctly selected a possible student answer but did not indicate any meaningful misconception of students. Although his statement reflects something about students' way of thinking, it does not demonstrate a sophisticated grasp of the specific misconception that students possess.

Analysis of the answers to Item 5 also revealed that 27% (n=22) of the teachers regarded the scientifically correct answer as incorrect (See Table 35). While teachers are expected to identify the incorrect answers that might be given by

students, they are also expected to identify the scientifically correct answer. However, 27% of the teachers depicted the scientifically correct option as a false answer given by students.

Table 35. Number of Teachers Choosing Each Option as Incorrect Student Answers

A (scientifically correct) n (%)	Only B, Only C, or B and C (scientifically incorrect) n (%)
22 (27%)	64 (69%)

For example, PT42 indicated that students might erroneously give the options A, B, and C to the question. However, option A cannot be given as a wrong answer by students since it is the scientifically correct answer. It can be argued that this result may give several clues about physics teachers' content knowledge about internal energy. Identifying the scientifically correct answer as an error might be regarded as an indication of teachers' own weak comprehension of internal energy.

PT2 correctly chose wrong student answers and provided sophisticated explanations regarding the misconception of students as follows: "(He) might think that their temperatures will be the same in the final because they receive equal amounts of heat…".

Item 6 presented physics teachers with a scenario in which a class of students makes investigations. After making investigations, students were asked a relevant question that they are expected to answer correctly. However, most of the students gave wrong answers. The item requested physics teachers to infer the alternative conception that leads students to make that mistake. The results of the analysis revealed that more than half of the physics teachers could not infer students' alternative conceptions (See Table 36). Answers of 42% of the physics teachers'

responses were classified as correct whereas answers of 45% of the physics teachers' were classified as false/irrelevant.

Table 36. Descriptive Statistics of Teacher Responses to Item 6

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.6	38 (42%)	45 (50%)	7 (8%)	90 (100%)

The physics teacher inferred six alternative conceptions that are relevant. The most inferred alternative conception by the physics teachers was "Items that heat up quickly are also ideal for keeping cold". All the alternative conceptions and the number of physics teachers who inferred them are presented in Table 37.

Table 37. Alternative Conceptions that are Stated by Teachers in Item 6

Alternative conceptions	n	%
Items that heat up quickly are also ideal for keeping cold.	14	16
Aluminum keeps cold because it feels colder.	8	9
Aluminum retains heat because it is solid/dense.	7	8
Aluminum retains heat better/Aluminum is an insulator.	5	6
Metals keep cold.	2	2
The foam loses heat due to its hollow structure.	2	2

Answers of the physics teachers classified as correct are presented in Table 38. PT 29 inferred the alternative conception "Aluminum is an insulator". PT 58 indicated the alternative conception "Items that heat up quickly are also ideal for keeping cold". PT 28 mentioned the solid and durable construction of aluminum as a source for alternative conceptions. PT 22 indicated that students might choose aluminum since they felt cold when they touched it.

Table 38. Examples of Teacher Responses to Item 6 Classified as Correct

	Teacher responses
PT 29	"Aluminum has better thermal insulation. They think that the foam material has a hollow structure."
PT 58	"If it heats better when heating (by looking at the temperature change), it stays colder when trying to keep it cold."
PT 28	"Since aluminum is strong and durable, it retains the temperature."
PT 22	"They answer as aluminum because it feels colder when they touch it."

Answers such as "Students did not learn the concepts", "They confuse conduction and insulation", "They did the experiment wrong and misinterpreted the results" were typical examples of false/irrelevant teacher answers.

Item 7 provided teachers with a scenario that includes a student answer to a teacher question. Physics teachers are expected to identify the alternative conception presented in the student answer. Almost all the teachers identified the erroneous student statement (See Table 39). They simply repeated the student statement "Temperature transfers from hot water to cold water" as the alternative conception of students. The item did not ask teachers to interpret the causes of student errors or come up with possible student answers that contain alternative conceptions. That may explain the very high correct answer rate of the item.

Table 39. Descriptive Statistics of Teacher Responses to Item 7

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.7	85 (95%)	3 (3%)	2 (2%)	90 (100%)

A typical answer that is given by teachers and classified as correct is as follows: "Temperature transfers from hot water to cold water". However, PT 14 did not just mention the erroneous student statement but interpreted the alternative conception as follows: "He confused the concepts of heat and temperature. He thought that

temperature could pass between substances". His statement was more in general terms rather than repeating the error.

The answer of PT 48 classified as false/irrelevant is as follows: "Normally, since the masses are equal, it becomes (80+60)/2=60. Since they do not know that the temperature of warm water depends on the mass… they can try to find the final temperature with long measurements". Although the physics teacher has pointed out a student difficulty that might exist in the subject, it was too general as well as irrelevant to be inferred from the student statement.

Item 8 requested physics teachers to infer student responses to a question about heat transfer. Teachers are again expected to come up with student responses that reflect alternative conceptions. The Item 8 presents a scenario in which a physics teacher asks students a question about how a bottle of lemonade with ice in it cools down. Most of the physics teachers (78%) inferred student answers that reflect alternative conceptions (See Table 40). 14% of the physics teachers gave false or irrelevant answers whereas 7% of the teachers left the item blank.

Table 40. Descriptive Statistics of Teacher Responses to Item 8

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.8	70 (78%)	14 (16%)	6 (7%)	90 (100%)

The most frequently stated alternative conception was "The coldness of ice passes into lemonade/The warmth of lemon passes into ice". Another alternative conception stated by the physics teachers was "The ice gave its heat to the water".

The physics teachers inferred three alternative conceptions in total. All the alternative conceptions that are inferred by the physics teachers and the number of teachers who inferred them are presented in Table 41.

Table 41. Alternative Conceptions that are Stated by Teachers in Item 8

Alternative conceptions	n	(%)
The coldness of ice passes into lemonade. / The warmth of lemon passes into ice.	43	47
The ice gave its heat/warmth to the water.	26	28
The heat of the lemonade has decreased. / The heat of the ice has increased.	11	12

Almost all the physics teachers whose answers are classified as correct inferred one alternative conception. Only eight teachers could come up with more than one alternative conception. For example, PT 10 correctly interpreted two alternative conceptions as follows:

> The ice melted and gave its heat to the lemonade. Thus, the lemonade became cold. The lemonade gave its heat to the ice, melting the ice. Thus, the lemonade became cold. The lemonade gave its heat to the ice, melting the ice.

A physics teacher response that was classified as false/irrelevant is depicted in Table 42. PT56 provided a false student answer. However, the answer does not reflect any alternative conception of the students. The answer of PT 48 also did not convey an informed understanding of student conceptions of heat transfer. PT 57 indicated that students might say weather conditions as a reason for the melting of ice, but this answer also does not reflect a sophisticated knowledge of student understanding.

Table 42. Examples of Teacher Responses to Item 8 Classified as False/Irrelevant

	Teacher responses
PT 56	"This event is the result of the energy transfer between the hot lemonade and the cold ice. A wrong answer that a student can give is that their internal energy is the same or that their temperatures are the same."
PT 48	"He may think that it is affected by the environment."
PT 57	"Student may consider the special state of matter and weather conditions that provide this or not".

Item 9 consists of two sections. The first section of the item is multiple-choice, and the subsequent section is open-ended. Only teachers who correctly answer the multiple-choice as well as the open-ended sections get a classification of correct. The item presents physics teachers a scenario in which an imaginary class has a discussion about why woolen clothes keep people warm. The physics teacher of the imaginary class requested students to give similar examples from their daily lives. Examples of three student answers are demonstrated in the question text. The physics teachers are expected to select the wrong answers that students may give. In addition, they are requested to explain alternative conceptions of students that might lead them to give wrong answers.

A high number of teachers correctly identified student examples that are incompatible with the warm-keeping mechanism of wool. 68% of the physics teachers indicated that students could make an incorrect explanation like Elif whereas 56% of the physics teachers indicated that students could make an incorrect explanation like Efe (See Table 43). Although Yeşim's explanation was correct and relevant, 12% of the physics teachers regarded her explanation as irrelevant to explain the warm-keeping mechanism of wool. This might imply that 12% of the physics teachers could not draw the similarity between woolen clothes keeping people warm and double-layered windows preventing heat loss.

Table 43. Frequency of Teachers Choosing Each Imaginary Student's Response as Incorrect

	Elif	Yeşim	Efe
n	61	11	50
%	68	12	56

Although more than half of the teachers accurately identified the students who gave incorrect examples, only a small number of teachers could accurately infer the alternative conceptions that might result in those erroneous statements (See Table 44). More than half of the physics teachers gave false/irrelevant answers and 4% of the physics teachers left the question blank.

Table 44. Descriptive Statistics of Teacher Responses to Item 9

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KSU.9	25 (28%)	61 (68%)	4 (4%)	90 (100%)

Many of the physics teachers whose answers were categorized as correct inferred the alternative conception "Woolen clothes warm people". For example, PT 14 made a correct interpretation as follows: "(They) may think that woolen clothes warm us up just like the heater warms us up".

A high number of teachers whose answers were categorized as false/irrelevant simply stated that "Students failed to fully understand the heat conduction coefficient". This statement might reflect something about students' understanding but does not truly demonstrate students' alternative conceptions that lead them to give erroneous examples.

The answer of PT 62 was also classified as false/irrelevant. By saying "The purpose is to prevent heat transfer", PT62 demonstrated that she understood the

purpose of the class discussion. However, the statement “They gave examples of the opposite situation in which heat transfer is rapid” is just a summary of the erroneous statements of students. The answer does not reflect any deep interpretation of the alternative conceptions that might result in students’ wrong comments.

Only a few teachers could correctly infer two alternative conceptions from the student statements. PT2, PT18, PT80, PT82 and PT92 interpreted the following two alternative conceptions from the students’ statements: “Woolen clothes warm people” and “Metals are conductors”.

Item 10 provided physics teachers with a scenario and requested them to infer the student’s alternative conception. The coding schema of this item includes partially correct in addition to correct and false/irrelevant. The decision of this inclusion was made after the analysis of the first and second round of cognitive interviews. The analysis of the interviews showed that teachers could make interpretations for this item that cannot be truly classified either as correct or false/irrelevant. For example, several teachers’ interpretations reflected a slight comprehension of students’ alternative conceptions or difficulties. However, those interpretations do not resemble the very exact alternative conception of students. Thus, it was decided to classify these answers as partially correct. As it can be seen from Table 45, only 16% of the physics teachers correctly answered the item. This implies that 14 teachers made an excellent interpretation of the alternative conception of the student. 36% of the teachers gave partially correct answers which implies a moderate comprehension of the student’s way of thinking. The remaining teachers either gave false/irrelevant answers (n=38) or left the item blank (n=5).

Table 45. Descriptive Statistics of Teacher Responses to Item 10

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
KSU.10	14 (16%)	32 (36%)	38 (42%)	5 (5%)	90 (100%)

The scenario in item 10 describes a student who thinks that a bucket of water and a pool full of water have the same heat. As indicated in the literature, students might think that heat is something that substances store or possess. In this regard, the student has the alternative conception of "Substances possess heat". Only a small number of teachers correctly inferred this alternative conception.

Responses that do not exactly reflect this alternative conception but demonstrate the related erroneous way of student thinking were classified as partially correct. For example, PT17 indicated that "…(The student) does not know that heat is transferred energy…". The teacher refers to a relevant way of student thinking but does not point out the core alternative conception that leads to the erroneous statement. For example, one might argue that the conception of "Heat is something possessed" might prevent students from comprehending the notion that "Heat is a transferred energy". In this regard, such teacher responses that are relevant but fail to cite the core alternative conception were classified as partially correct.

Contrary to Item 7, Item 10 requests teachers to interpret the causes of a wrong student conclusion. Thus, teacher responses that just repeat or paraphrase the student answer were classified as false/irrelevant. For example, PT 28 indicated that "Objects with the same temperature have the same heat energy" as the alternative conception of students. However, this statement does not convey any deep interpretation of students' way of thinking. Rather than merely repeating the wrong student conclusion, the physics teachers were expected to answer the question of

"Why do students think that objects with the same temperature have the same heat?". In this regard, answers like PT 28's were categorized as false/irrelevant.

When PT 28's answer to Item 1 was analyzed, it was observed that PT 28 might possess the core alternative conception. His statement "…(The student) should have said that K's heat has decreased, L's heat has increased…" implies that the teacher might also incorrectly think that substances possess heat. Hints given from PT28's answer to Item 1 might verify the classification of his answer to Item 10 as false/irrelevant.

Most of the physics teachers whose answers were classified as false/irrelevant simply stated that "Students confuse/misunderstand heat and temperature". Although this statement reflects an understanding of students' way of thinking, it does not demonstrate a sophisticated grasp of the reasons for the wrong student statement. In fact, the item requested the physics teachers to indicate why the student believes that a bucket full of water and a pool full of water have the same heat energy. Simply stating that students misuse heat and temperature concepts does not convey the reasons behind the students' mistakes. As it can be seen from PT28 and several teachers who were interviewed, this interpretation also does not ensure teachers have the knowledge that "Substances cannot have heat".

Item 11 presented physics teachers with a student quote about internal energy. In the scenario, the student was commenting as if internal energy depends only on temperature. In this regard, the physics teachers are expected to infer the alternative conception of the student. Many of the physics teachers correctly interpreted the student statement and indicated the alternative conception (See Table 46).

Table 46. Descriptive Statistics of Teacher Responses to Item 11

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
K.SU11	71 (79%)	14 (16%)	5 (5%)	90 (100%)

The most frequently stated alternative conception was "They think that internal energy depends only on temperature/They ignored the mass of the substances". PT provided a more detailed explanation as follows: "The student only compared the kinetic energy between molecules depending on temperature. He ignored the potential energy of the molecules or particles that make up the substance, depending on their quantity". PT 36 did not only mention the alternative conception, but also shared the definitions of energy types that constitutes internal energy.

Examples of false/irrelevant teacher responses are presented in Table 47. PT 48 did not mention internal energy and argued that students might think that the higher the temperature, the higher the heat. His explanation was not relevant and classified as false/irrelevant. PT 67 just repeated a question, and PT 13 made an irrelevant comment about internal energy change. Both of their answers were classified as false/irrelevant.

Table 47. Examples of Teacher Responses to Item 11 Classified as False/Irrelevant

	Teacher responses
PT 48	"He takes into account that the heat of the one with higher temperature will also be higher. He does not think about the heat formula."
PT 67	"Does the one with higher temperature have more internal energy?"
PT 13	"Internal energy depends on temperature change, not temperature. Forgets that temperature is proportional to the speed of molecules."

Item 12 provided physics teachers with a scenario that describes student statements about icicles exposed to sunlight. The item mainly requested teachers to infer the alternative conception "The temperature of every substance that receives heat increases". In addition, student statements that reflect the alternative conception "Substances possess heat" were also included in the item. Responses of the physics teachers who inferred both two alternative conceptions were classified as correct. Responses of physics teachers who came up with only one alternative conception were classified as partially correct. The results of the analysis revealed that 37% of the teachers inferred both alternative conceptions whereas 43% of the teachers inferred only one alternative conception (See Table 48).

Table 48. Descriptive Statistics of Teacher Responses to Item 12

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
KSU.12	33 (37%)	39 (43%)	13 (14%)	5 (5%)	90 (100%)

The answer of PT 56 which is classified as correct is as follows: "There is no such concept as the heat of an object. Since we do not know whether the substance changes state or not, we cannot say anything about its temperature". PT56 correctly inferred both alternative conceptions from the student statements. The teacher acknowledged the wrong statement of students as "Heat of substances" as well as students' definite judgment about the temperature change of icicles.

Another teacher response classified as partially correct is as follows: "… (The student) may not know that the temperature remains constant during phase changes such as melting-freezing etc.". PT73 only inferred one alternative conception of temperature change and did not mention student statements about heat of icicle.

Several teachers stated that students did not understand internal energy and had alternative conceptions of heat and temperature without delving into the details of student conceptions. An example of such a response which is classified as false/irrelevant is presented in Table 49. The answer of PT 13 was also classified as false/irrelevant since she did not mention the two alternative conceptions of heat and temperature but commented only about density.

Table 49. Examples of Teacher Responses to Item 12 Classified as False/Irrelevant

	Teacher responses
PT 38	"Students do not know the concept of internal energy. They have misconceptions about heat and temperature."
PT 13	"When water drops freeze, the volume increases, but the density decreases since the mass does not change."

4.1.2.3 Results of the knowledge of instructional strategies section of the PCK-H&T instrument

In this section, the results of the Knowledge of student understanding section of the PCK-H&T instrument are presented item by item.

Item 1 presented physics teachers with a scenario in which a physics teacher candidate prepares a lesson plan built on the following alternative conception of students: "All metals have the same specific heat". First, the physics teachers were expected to suggest the physics teacher candidate an experiment that can be designed within the scope of the aim of the lesson. The second section of the item requested the physics teachers to come up with reasons to integrate students' alternative conceptions into lesson plans. The results of the analysis revealed that the physics teachers designed experiments in which the specific heat of two different metals was investigated and compared (See Table 50). Specifically, almost all the physics

teachers could successfully design an experiment that falsifies an incorrect student conception. Only 6% of the physics teachers could not design a proper experiment and 12% of the physics teachers left the item blank.

Table 50. Descriptive Statistics of Teacher Responses to Item 1.a

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.1a	74 (82%)	5 (6%)	11 (12%)	90 (100%)

The answer of PT 22 which represent a typical coorect answer is as follows: "Heating the same mass of different metals with identical heaters and measuring their temperature changes".

On the contrary to the first section of Item 1, nearly half of the physics teachers' responses to the second section were classified as either false/irrelevant or blank (See Table 51). The physics teachers were expected to state the possible reasons for considering alternative conceptions while designing lessons. The results indicated that slightly more than half of the physics teachers could not come up with sophisticated explanations about the importance of taking student conceptions into account.

Table 51. Descriptive Statistics of Teacher Responses to Item 1.b

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.1b	43 (%48)	33 (%37)	14 (%16)	90 (100%)

A teacher response to Item 1.b classified as correct is as follows: "To draw attention to misconceptions, to correct the mistakes they know as true and to prevent misconceptions. To ensure that they find the truth through their own experiences. To

increase the permanence of learning by doing and experiencing". PT 14 mentioned the importance of pointing out the alternative conceptions, enabling students to find out the truth through their own experiences and the influence of learning by doing on permanent learning.

Another teacher response that was classified as correct is as follows: "To destroy students' learned rote thoughts. It is more difficult to destroy false learning than to teach new information". Apart from the importance of changing the memorized conceptions of students, PT 44 also mentioned the difficulty of changing the already established alternative conceptions compared to formulating new ones.

Although nearly half of the physics teachers gave sophisticated answers to Item 1.b, the remaining teachers gave unsophisticated or irrelevant answers (n=47). For example, PT 73 mentioned the importance of providing students with knowledge about metals and thermal conductivity in technology and industrial designs. Although this idea might represent a lesson objective, no valid arguments about integrating alternative conceptions into lesson plans were made.

Several teacher responses that were classified as false/irrelevant are as follows: "Being influenced by the discourse that metals have good thermal conductivity in science or chemistry classes" (PT 58), "Understanding specific heat" (PT 33), "The same type of metals can be used" (PT 48), "The idea that all metals have the same specific heat" (PT 43). None of these responses depict any sophisticated grasping of the importance of integrating students' alternative conceptions into lessons. PT 33 just mentions the general aim of a lesson and, PT 58 and PT 43 merely repeat the incorrect student conceptions.

Responses of the physics teachers classified as correct demonstrated the basic tenets of student-centered learning approaches. Most of the physics teachers used the

term ‘alternative conceptions’ which implies that they are aware of one of the most fundamental elements of conceptual learning. The most frequently given answer to Item 1.b was changing students’ alternative conceptions with scientifically correct ones. Other reasons indicated by teachers were taking students’ attention, making them surprised and providing them with a student-centered learning environment which enhances permanent learning.

The overall results of the analysis of Item 1 suggest that the physics teachers successfully design experiments to correct false student ideas. On the other hand, they demonstrated a comparatively lower level of performance when they were expected to express the importance of considering student conceptions while designing lessons. This might be explained by the structure of traditional classrooms. Generally, teachers tend to immediately correct false student responses rather than delve deeper into student understandings This might be explained by a variety of teacher-, school- and system-related factors such as time restriction, adopting direct instructional methods etc.

Item 2 presented the physics teachers with a description of an analogy. The physics teachers were asked to infer which quantity the analogy is used to explain. Basically, the analogy is used to describe ‘temperature’. In the analogy, the corn grains heated in a pot on the stove start to move and hit the sides of the pot. This is similar to the increase in the kinetic energy of particles of a matter which is heated. The results of the analysis indicated that 46% of physics teachers correctly inferred temperature (See Table 52). However, more than half of the physics teachers either gave irrelevant answers or left the item blank (n=47).

Table 52. Descriptive Statistics of Teacher Responses to Item 2.a

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.2a	41 (%46)	39 (%43)	10 (%11)	90 (100%)

The second section of the item requested the physics teachers to interpret the limitations of the analogy. Only a few teachers could correctly interpret the limitations of the analogy (n=16). The majority of the teachers (%56) either gave false/irrelevant answers or left the item blank (See Table 53).

Table 53. Descriptive Statistics of Teacher Responses to Item 2.b

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.2b	16 (%18)	50 (%56)	24 (%27)	90 (100%)

Despite the low number of physics teachers who correctly inferred the limitations of the analogy, several insightful interpretations were made by the physics teachers. These interpretations can be classified under three main points. One group of physics teachers drew attention to the inefficacy of the analogy to explain the state change of the matter. The kinetic energy of the particles does not increase when the matter is changing its state. Thus, this analogy might contribute to an improper understanding such as “The temperature of objects receiving heat always increases”. Several teacher responses that depict this limitation are presented in Table 54.

Table 54. Teachers' Interpretations of the Limitation of the Analogy about State of Change

	The response of the physics teacher classified as Correct
PT 58	"He tried to say that the temperature of the heating substance increases and the substance receiving the heat moves. But he could not explain the temperature remaining constant during the phase change with this analogy."
PT 32	"We cannot use this in a phase change because the temperature of the particles will not increase when heat is given."
PT 57	"The absorption of heat by a substance causes its temperature to increase. However, this analogy cannot explain why the temperature remains constant during a phase change."

Another remarkable interpretation of the physics teachers was the analogy's limitation to correctly explain the motion of the particles. As the matter is given heat, the average kinetic energy of the particles increases. However, corn kernels stop after popping. This might create a perception that particles of matter might stop moving. Several teacher responses that depict this limitation are presented in Table 55.

Table 55. Teachers' Interpretations of the Limitation of the Analogy about Motion of the Particles

	Teacher responses
PT 68	"The kinetic energy of the substance whose temperature increases also increases. However, since the movement of the corn will slow down after it pops, it cannot fully explain the event."
PT 8	"At the point where the movement ends, the corn grains stop. However, the particles in the substance are in motion."
PT 7	"After corns popped, their movements stop."

The third interpretation was about the type of the change particles have. The analogy simply intends to convey the change of the motion of particles as the matter is heated. However, a chemical change is observed in the analogy: The structure of the corn grains changes as they receive heat. This might create a conception that equates or confuses heat intake with chemical change. The PT 70 mentioned this limitation

as follows: “The corn looks different before and after it pops. The student can expect a change in shape and color”.

A high number of teachers either gave false/irrelevant answers to Item 2.b (%56) or left the item blank (%27). These responses do not reflect any sophisticated grasps of the limitations of the analogy. Repetitions of the definition of temperature or general descriptions of the limitations of analogies can be stated as examples that fall under the false/irrelevant category. For example, PT 1 indicated that the analogy might not be properly understood or misunderstood by the students. Although this response might reflect the general limitations of analogies, no specific and sophisticated interpretations regarding the context were made.

Item 3 presented a scenario in which a physics teacher asks his/her students to conduct an experiment about thermal equilibrium. Two different methods are suggested by the physics teacher to his/her students. The students could either use real laboratory materials or a simulation. The physics teachers are requested to explain the advantages of using simulations over real laboratory materials. Only 32% of the physics teachers came up with a relevant advantage of using simulations over real laboratory materials (See Table 56). More than half of the teachers gave false/irrelevant answers or left the item blank.

Table 56. Descriptive Statistics of Teacher Responses to Item 3

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.3	29 (32%)	53 (59%)	8 (9%)	90 (100%)

The advantages of using simulations over real laboratory materials stated by the physics teachers were categorized under three categories. The most frequently cited

advantage of using simulations was “Eliminating the effects of the heat loss” (n=22). Other advantages of using simulations that were stated by the physics teachers were “Safer since not working with substances in high temperatures” (n=5) and “Easily changing the parameters such as volume of the substances” (n=2).

Answers of the physics teachers who stated simulations’ advantage of reducing the influence of confounding variables are presented in Table 57. For example, PT 25 stated that “(Simulations) give more accurate results since heat loss is neglected”. PT 25 correctly analyzed the heat loss as the confounding variable of the experiment.

Table 57. Teacher Responses about the Influence of Confounding Variables

	Teacher responses
PT 25	“(Simulations) give more accurate results since heat loss is neglected.”
PT 18	“Since it will be difficult to create an ideal environment, room temperature will affect the result of the experiment in the first method. The experiment may not show the real value due to the possibility that the scale may not make precise measurements.”
PT 4	“In the first method, thermal insulation is not fully provided, and clear results are not achieved.”

Another advantage of using simulations is the ease of changing parameters. Two physics teachers mentioned this specific advantage in a context-related manner. In other words, they explicitly expressed the opportunities simulations provide while conducting a heat equilibrium experiment. These specific advantages were cited as easily arranging the mass, temperature, and kind of liquids. The responses of these teachers are shown in Table 58.

Table 58. Teacher Responses about the Advantage of Easily Changing Variables

	Teacher responses
PT 28	"In the simulation, the mass and temperature of the water can be adjusted as desired."
PT 63	"In the second method, the type and amount of liquids can be changed. More examples can be given."

There were also several physics teachers who expressed the less risky nature of simulations in a more context-related way. Two physics teachers mentioned the risks the experiment in the scenario can cause. Specifically, these physics teachers mentioned the risks the hot water may cause such as injuries among students. The answers of these teachers are depicted in Table 59.

Table 59. Teacher Responses about the Advantage of Reducing the Risks of the Experiment

	Teacher responses
PT 58	"90 degrees water is quite hot. Students may get hurt."
PT 68	"It is safer because students do not work directly at high temperatures."

The physics teachers are expected to state the advantages of using simulations while conducting an experiment of heat equilibrium. Thus, all the answers that are classified as correct refer to the use of simulations in a specific context. Several teachers stated only the advantages of using simulations without considering the context of the question. Stating the general advantages of using simulations such as "Reduces risk", "Reduces cost" and "Provides ease" does not illustrate a grasp of the content of the question. Thus, the answers of these teachers were classified as false/irrelevant. For example, PT 42 simply stated that "It is harder to make mistakes in simulation. Someone more experienced is doing the simulation". Her explanation does not refer to the specific experiment used in the simulation.

The Item 4 presents the physics teachers with a scenario in which a student wants to investigate the cooling rate of matter. The student hypothesizes that the volume and surface area of matter affect its cooling rate. For this purpose, the student investigates the cooling rate of two different tanks filled with water. In this regard, the item asks the physics teacher to interpret the scientific application feature that the student has neglected in his experiment. Basically, the basic problem of the student's experimental design was the values of the variables that the student has chosen. Since the student aims to investigate the influence of two variables on another variable, the students had to keep one factor constant and vary only the other variable at a time. However, in his/her design, no variables are kept constant or in other words, controlled. Thus, he/she cannot find the single effect of volume or surface area on cooling rate.

The results of the analysis revealed that 50% of the physics teachers correctly interpreted the weakness of the student's experimental design (See Table 60). This means only half of the physics teachers could correctly infer that the student did not systematically vary variables and in fact did not understand the control mechanism of true experiments. The remaining teachers either gave false/irrelevant answers or left the item blank.

Table 60. Descriptive Statistics of Teacher Responses to Item 4

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.4	45 (50%)	35 (39%)	10 (11%)	90 (100%)

Teachers who correctly answered Item 4 interpreted the weakness of the student's experimental design in terms of his/her misuse of the control variables. Teacher

expressions such as “(The student) tried to examine more than one variable at the same time. He/she could not create a controlled experimental setup” (PT 35), “It would be difficult to measure the impact of two variables simultaneously. It would be better to keep one constant and investigate the effect of the other” (PT 31) clearly demonstrate that these teachers have a sophisticated understanding of the nature of true experiments.

All responses of the physics teachers that were classified as correct mentioned the main problem regarding the student’s choice of the values of the variables. However, there were also several physics teachers who gave scientifically correct answers but did not necessarily point out the main problematic part of the student’s experimental design. For example, several physics teachers indicated that the student should have also considered other variables such as the temperature difference between the tanks and the environment and the materials that the tanks are made of. In fact, these factors may have an impact on the results of the experiment. However, even if the student has controlled for these and other numerous variables, his choice of values of the variables of volume and surface area is still problematic. In other words, even if the student considered controlling all possible confounding variables, he could not get any meaningful results with his experimental setup. In this regard, it can be said that this kind of responses that mention other confounding variables demonstrates a less sophisticated understanding of true experiments. Thus, they were classified as false/irrelevant. Table 61 presents several examples of such teacher responses.

Table 61. Examples of Teacher Responses to Item 4 Classified as False/Irrelevant

	Teacher responses
PT 3	"Environments with temperature differences between in and out of the environments should be used."
PT 56	"He neglected the internal temperatures and thicknesses of the containers."
PT 53	"He should state the type of materials from which the warehouses are made."

Although responses depicted above were classified as false/irrelevant, some essential aspects of the experimental processes were mentioned in them. However, several physics teachers just repeated the expected results or mentioned the amount of liquid as a confounding variable (See Table 62). Since the student in the scenario investigated the influence of the volume of the water, the latter response might reflect teachers' misunderstanding of the item.

Table 62. Other Examples of Teacher Responses to Item 4 classified as False/Irrelevant

	Teacher responses
PT 73	"As a result of the experiment, he can see that the cooling rate depends on the surface area. He can see that evaporation does not depend on the amount of substance."
PT 59	"The amount of water in the containers is not equal."
PT 25	"The amounts of the ingredients should be different."

Item 5 depicts an activity which is labeled as an experiment in a schoolbook. In the activity, a bottle with a balloon attached is placed in a bowl filled with hot water. Over time, the balloon will be seen to inflate. The physics teachers are asked to interpret why the activity cannot be characterized as a true experiment. The physics teachers were expected to evaluate the lack of a systematic variation of a variable in the activity. The results of the analysis suggest that a small number of physics teachers gave a correct answer (See Table 63). 53% of the physics teachers gave

false/irrelevant answers and a very high number of teachers (%26) left the item blank.

Table 63. Descriptive Statistics of Teacher Responses to Item 5

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS 5	19 (21%)	48 (53%)	23 (26%)	90 (100%)

PT 44's answer reflects a true identification of why the activity cannot be a real experiment. PT 44 mentions the importance of systematically changing a variable and investigating its influence with these words:

> In experiments, we measure the effect of various variables on a quantity. In this experiment, a variable situation or quantity is not examined. It is the same as observing ice melting. There is no measurement, no control of the variable.

Examples of teacher responses that are classified as correct are illustrated in Table 64. PT 59, whose answer was also classified as correct, suggested forming control groups to turn the activity into a true experiment. Specifically, she suggested putting water of different temperatures into another bowl. It can be said that her answer reflects a sophisticated grasp of the nature of true experiments. In a similar vein, PT 52 stated the necessity of changing the independent variable to see the effects on the dependent variable.

Table 64. Examples of Teacher Responses to Item 5 Classified as Correct

	Teacher responses
PT 59	"For an experiment to be possible, there must be dependent variable groups. For example, water with a different temperature should be placed in another container."
PT 52	"The the independent variable should be varied and its effect on the dependent variable should be clearly revealed."

Most of the physics teachers gave less sophisticated answers to Item 5 (See Table 65). Several teachers mentioned key experiment features that they thought were missing in the activity such as research aim, hypothesis, and materials. Despite being important for the experimentation process, these elements cannot ensure an activity is a true experiment. This kind of answers might also reflect teachers' perceptions of true experiments. The physics teachers might consider formulating hypotheses or collecting data as distinct and unique features of true experiments. However, the distinct feature of true experiments is the systematic variation of a certain variable. In this regard, the abovementioned responses were classified as false/irrelevant. Below are several examples of such responses.

Table 65. Examples of Teacher Responses to Item 5 Classified as False/Irrelevant

	Teacher responses
PT 50	"The purpose of the experiment is not stated, no hypothesis statement is made."
PT 17	"The experimentation steps, tools and equipment and basic explanations are not given."

Several teachers focused on comparatively unimportant details such as the lack of thermal insulation in the environment or the ambiguity of factors such as the size of the bottle, the amount of air in it, and the temperature of the environment (See Table 66). Although specification of these factors is important in true experiments, this alone cannot be sufficient to label activities as true experiments. In other words, ensuring thermal insulation and specifying the values of each variable would not make the activity a true experiment.

Table 66. Examples of Teacher Responses to Item 5 Classified as False/Irrelevant

	Teacher responses
PT 69	"It is desired to prove that heated air expands. However, a large glass container gives off heat. Healthier results are obtained in a heat-insulated environment."
PT 53	T"he size of the bottle, the amount of air inside and the temperature of the environment are effective in the experiment. The temperature of the poured water should be measured with a thermometer. Since these conditions are not provided in the classroom environment at school, the exact desired observation could not be made."

Other irrelevant answers were about the limitations of the experiment, the stance of the bottle, the long time that take the balloon to inflate, the possibility of pressure drop, the neglect of the evaporation of water and just a repetition of what would have been observed. Several examples of such teacher responses are illustrated in Table 67.

Table 67. Examples of Teacher Responses to Item 5 Classified as False/Irrelevant

	Teacher responses
PT 25	"Limitations are not specified."
PT 3	"The bottle cannot stand upright, the volume change due to temperature change occurs in a short time".
PT 4	"The balloon's inflation may be due to both air expansion and pressure drop."
PT 9	"Evaporation of water is ignored."
PT 42	"The air inside expands with pressure and temperature and the balloon inflates."

Item 6 presents the physics teachers an analogy that can be used in instruction. The format of the item is closed-ended. The physics teachers are expected to infer the quantities that were aimed to be taught with this analog. One quantity and its correspondence in the analogy was explained to the physics teachers. The physics teachers were requested to interpret the remaining two quantities that were used in the analogy which are heat capacity and conductivity. In each item option, two

quantities are depicted, and the physics teachers were expected to choose the correct option (heat capacity-conduction). The results of the analysis suggest that only 29% of the physics teachers correctly inferred the quantities (See Table 68). In total, 71% of the physics teachers gave incorrect answers or left the item blank.

Table 68. Descriptive Statistics of Teacher Responses to Item 6

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS 6	26 (29%)	48 (53%)	16 (21%)	90 (100%)

The second option which was mostly chosen by the physics teachers was 'internal energy-conduction' (n=22). When the physics teachers' statements from the interviews were also considered, it can be said that the physics teachers made the connection about conduction more easily compared to heat capacity.

Item 7 presents the physics teachers with a description of a demonstration. The physics teachers are asked what inferences the students should make with this demonstration. In other words, they were asked to interpret the aim of the demonstration. Basically, the movement of food dye in three bottles of water with different temperatures was compared. The physics teachers were expected to make inferences about the movement of particles in hot vs. cold matter, the relation between temperature and speed of the particles, etc. The results of the analysis revealed that nearly half of the physics teachers correctly interpreted the aim of the demonstration (n=43). However, 52% of the teachers either gave false/irrelevant answers or left the item blank (See Table 69).

Table 69. Descriptive Statistics of Teacher Responses to Item 7

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS 7	43 (48%)	37 (41%)	10 (11%)	90 (100%)

The answer of PT 44 classified as correct is as follows: “To show that the motions (kinetic energies) of atoms and molecules in hot objects are greater than in cold objects”. PT 44 correctly interpreted the aim of the activity as to demonstrate that “Movements of particles in hot objects are faster than in cold objects”.

Nearly half of the physics teachers (n=43) either mentioned the movement, speed or the kinetic energy of the particles and its increase with temperature. Table 70 presents several examples of teacher responses that were classified as correct.

Table 70. Examples of Teacher Responses to Item 7 Classified as Correct

	Teacher responses
PT 46	“Hot water molecules have more kinetic energy than cold water molecules.”
PT 53	“As the temperature of the substance increases, the kinetic energy of its molecules increases. This speeds up the molecules. Its internal energy increases. Therefore, the dye spreads more easily in water.”
PT 23	“Particles of matter with high kinetic energy move faster and vice versa.”

Several teachers indicated other inferences that students may make with the demonstration. These inferences were about other topics of physics such as density, dissolution, surface tension and diffusion (See Table 71). For example, PT 58 indicated that the food dye in hot water would reach the bottom faster since the density of the hot water is lower. In a similar vein, PT 48 indicated that temperature increases dissolution. These kinds of interpretations may reflect scientifically valid points. However, the items of the test were written for the heat and temperature topic.

In this vein, the physics teachers were expected to make interpretations about this topic. Giving off-topic responses to the item might give clues about the levels of physics teachers' knowledge of the aim of the demonstration. One may argue that these teachers could not focus the demonstration from a heat & temperature lens and as a result make explanations from other topics. This may be explained by the topic-specific nature of PCK. Teachers may have different levels of PCK for different topics; they could more easily assign an aim to an activity for specific topics that they possess higher PCK. Since these teachers interpreted the demonstration for a different topic, their answers were classified as false/irrelevant.

Table 71. Examples of Teacher Responses to Item 7 Classified as False/Irrelevant

	Teacher responses
PT 58	"The density of food dye is high, meaning it will want to reach the bottom. The density of hot water is low. The dye reaches the bottom more easily. This is why it dyes more quickly."
PT 48	"She may have shown that temperature speeds dissolution."
PT 47	"The effect of temperature on surface tension."

Other teacher responses that were just a repetition of the demonstration or indicate an irrelevant purpose were classified as false/irrelevant. For example, answers like "Explaining the effect of temperature" (PT 11), "Substances spread faster in hot water" (PT 56), "…(The teacher) may have tried to show that if temperature is high, the evaporation rate is also high" (PT 34) illustrates no meaningful insight regarding the purpose of the demonstration.

Item 8 depicts a description and a visual illustration of an activity used in a physics class. The item is closed-ended and requests the physics teachers to choose several physical events that can be explained by the demonstration. The illustration was a typical example of convection which is one of the heat conduction ways. The

physics teachers were first expected to interpret the physical event occurring in the activity which is convection. Then, they should have analyzed the options whether they were an example of convection. Five of the item options were an example of convection whereas two of them were an example of radiation. The physics teachers were expected to choose five options that are examples of convection. The physics teachers who correctly identified 5, 4 and 3 examples of convection were classified as correct. On the other hand, if they correctly identified 2, 1 or 0 examples as convection, their answer was classified as false/irrelevant.

The results of the analysis revealed that one-third of the physics teachers could correctly identify five, four or three physical events as examples of convection (n=30). Slightly more than half of the teachers correctly identified two, one or zero examples of convection. (See Table 72).

Table 72. Descriptive Statistics of Teacher Responses to Item 8

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.8	30 (33%)	50 (56%)	10 (11%)	90 (100%)

Several examples of convection were identified by more physics teachers whereas others were identified by less physics teachers. “Heating a room with a stove” was the convection example that a very high number of physics teachers correctly identified (n=57). This example was followed by “Formation of breeze winds” (n=36) and “Movement of the magma fluid” (n=35). A list of the physical events of convection and the number of physics teachers correctly identified them is presented in Table 73.

Table 73. Number of Teachers Correctly Identified Each Example of Convection

Physical events	n
Heating a room with a stove	57
Formation of breeze winds	36
Movement of the magma fluid	35
Working of hot air balloons	34
Thawing frozen meat	18

Item 9 presents the physics teachers with a description and an example of cognitive conflict. The item is multiple-choice, and the options consisted of several examples that might lead or not lead students to experience cognitive conflict. The physics teachers first have to comprehend what cognitive conflict is and then interpret the options in terms of their possibility of causing cognitive conflict. In other words, physics teachers have to choose options that lead students to experience cognitive conflict. Two of the items were examples of cognitive conflict whereas the remaining two items were examples of simple physical events. The physics teachers were expected to choose at least one option that is an example of cognitive conflict and not to choose options that are examples of simple physical events. One might argue that if they choose options about simple physical events, they either did not understand what cognitive conflict is or have incorrect knowledge of student alternative conceptions. In this regard, while scoring the items, the physics teachers who had chosen one or two options about simple physical events did not get any points and their answers were classified as false/irrelevant. On the other hand, the physics teachers who did not choose options about simple physical events and chose at least one or two options about cognitive conflict got points. Their answers were classified as partially correct or correct, respectively.

The results of the analysis suggest that more than half of the physics teachers (n=51) gave false/irrelevant answers or left the item blank (See Table 74). Answers

of 23% of the physics teachers were classified as correct whereas answers of 20% of the physics teachers were classified as partially correct. This implies that 23% of the physics teachers correctly chose the two options about cognitive conflict and did not choose any option about simple physical events. In a similar vein, 20% of the physics teachers correctly chose one option about cognitive conflict and did not choose any option about simple physical events.

Table 74. Descriptive Statistics of Teacher Responses to Item 9

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
KIS.9	21 (23%)	18 (20%)	40 (45%)	11 (12%)	90 (100%)

The options that depict physical events about cognitive conflict were “Covering a piece of ice with wool and measuring the temperature change” and “Adding ice to water at 0 °C and measuring the temperature change of the water”. These two physical events are typical examples that lead to cognitive conflict among students. Students generally think of wool as a heating material and do not consider its insulator nature. Thus, they think that if a piece of ice is covered with wool, it will melt. When they observe that the wool prevents ice from melting, they experience a cognitive conflict. Similarly, students think that if ice is added to water at 0 °C, its temperature will decrease. However, the temperature of the water will not change because of its state of change. When students do not observe any change in the temperature of the water, they experience cognitive conflict. The remaining two options were “Measuring the temperature change of water by placing a hot metal spoon into it” and “Comparing the temperatures at which frozen olive oil and ice begin to melt”. These simple physical events are not expected to lead to any

cognitive conflict among students. Thus, the answers of the physics teachers who chose one or two of these options were classified as false/irrelevant even if they chose one or two options about cognitive conflict.

Specifically, the physics teachers who did not choose any of the options about simple physical events and chose one of the options about cognitive conflict had a classification of partially correct. The physics teachers who did not choose any of the options about simple physical events and chose two of the options about cognitive conflict had a classification of correct. The physics teachers who chose one or two options about simple physical events had a classification of false/irrelevant even if they chose one or two options about cognitive conflict.

Item 10 presents an activity poster prepared by a physics teacher. The activity requested students to design houses for penguins to protect them from the effects of global warming. The materials that are used during the activity are also given. The physics teachers are asked to write their suggestions to make the activity more suitable for scientific investigation steps. Basically, the physics teachers are expected to integrate a control mechanism to the activity such as increasing the materials that are used to make a house for the penguins. By this way, students could investigate the most suitable materials that keep a house warm. The results of the analysis suggest that %23 of the physics teachers correctly answered the item (See Table 75). Item 10 is the question with the highest blank response rate. This might imply that the physics teachers find the item difficult to understand.

Table 75. Descriptive Statistics of Teacher Responses to Item 10

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.7	21 (23%)	38 (42%)	31 (34%)	90 (100%)

Table 76 shows two teacher responses that are classified as correct. PT 53 suggested diversifying materials that are used to make houses and making comparisons by measuring the temperatures of houses in time. His suggestion reflects the features of controlled experiments. PT 31 designed an experiment and explained each phase of the experiment. In the experiment phase, he used the phrase "Wool and other materials" implying his use of a control mechanism. In fact, he wrote the expected results of the experiment in terms of comparing the melting of ice in houses covered with different materials. In a similar vein, PT 59 suggests using other materials than wool fabric. PT 18 did not suggest using different materials but still emphasized the use of a control mechanism. He suggested comparing the temperature difference between an uncovered ice and an ice covered with wool. Thus, his answer reflects the core elements of a controlled experiment.

Table 76. Examples of Teacher Responses to Item 10 Classified as Correct

	Teacher responses
PT 31	"Since wool fabric is a good insulator, when we wrap ice with wool fabric, heat has difficulty passing through the ice and the ice melts in a longer time. By wrapping the ice with wool and other materials, the temperatures of the ice after an equal amount of time are measured with a thermometer."
PT 53	"Materials can be diversified together with the student. By forming groups and making houses from different materials, students can measure the temperatures of the houses at certain intervals in the same environment and observe which material is most suitable for the penguins. The heat insulation of the materials they choose is examined. A penguin house can be made by choosing the right material."
PT 59	"The teacher should not only use wool fabric, but he should also diversify the materials."
PT 18	"The temperature change between a piece of ice wrapped in wool fabric and a piece of ice without any insulation is examined. It is seen that the temperature change graph of the ice piece wrapped in wool fabric has a lower slope than the temperature change graph of the ice piece without any insulation."

Several teachers treated ice cubes as a material used to design houses. As a result, they did not suggest other materials to make a controlled experiment. However, they

still emphasized the use of a control mechanism by comparing the temperature differences of different houses. For example, PT 68 suggested comparing the temperature differences between a house made of ice cubes and another one covered with wool fabric. Similarly, PT 44 suggest tracking the temperature change in two different houses built with ice cubes and wool fabric. Answers that reflect this kind of comparison are categorized as correct and presented in Table 77.

Table 77. Other Examples of Teacher Responses to Item 10 Classified as Correct

	Teacher responses
PT 68	"Students may be asked to build a house using only ice cubes, then to build a house using ice cubes and wool fabric. They may be asked to measure the temperature of each and find out which is most effective in protecting the penguins from the heat."
PT 44	"First, students are asked to guess the best insulation material. Then, they make a house with both ice pieces and wool fabric, put an object inside them and measure the temperature of the objects after a while. Then, the physical reasons for the difference are explained."

Several teacher responses that are classified as false/irrelevant are presented in Table 78. Most of the physics teachers who gave false/irrelevant answers focused on more superficial details and neglected the control mechanism of the experiments. For example, PT 22 described an activity that can decrease the heat conduction rate. However, the teacher focuses on designing a single house and does not emphasize the importance of making comparisons between different materials. In this regard, her answer is classified as less sophisticated and categorized as false/irrelevant. Similarly, PT 62 made less relevant suggestions such as giving sources about data collection. PT 45 made a too general suggestion, and PT 50 made no suggestion and regarded the activity as sufficient. PT 13 and PT 29 just summarized the phases of experiments and made no sophisticated suggestions that may enhance the quality of the activity.

Table 78. Examples of Teacher Responses to Item 10 Classified as False/Irrelevant

	Teacher responses
PT 22	"By using ice in multiple layers to provide thermal insulation, the heat conduction rate can be reduced."
PT 62	"Places to conduct research regarding the data collection phase can be written."
PT 45	"Regulations can be made on measures to reduce global warming."
PT 50	"This activity is sufficient for the purpose."
PT 13	"First, students are informed about the subject. They are asked to make observations. Then, an experiment is conducted and how successful it is in heat insulation is measured."
PT 29	"Students conduct experiments and evaluates results."

Item 11 presents the physics teachers with a scenario in which an imaginary physics teacher wants to teach her students the scientific experimentation process. In this regard, the imaginary physics teacher wants her students to make an investigation about heat conduction. The physics teachers were requested to identify the experimentation phases. Specifically, they were requested to make five interpretations. First, they were requested to identify a phase as identification of the problem. Then, they had to write a hypothesis and identify the phase of planning of the experiment. Finally, they had to identify the experimentation phases of collect data and analyze and interpret the results. Answers of the physics teachers who correctly identified all of the five phases were classified as correct. Answers of the physics teachers who correctly identified three or four phases were classified as partially correct. Finally, answers of the physics teachers who correctly identified two, one or zero phases were categorized as false/irrelevant. The results of the analysis revealed that only 11% of the physics teachers could correctly identify all the experimentation phases (See Table 79). 37% of the physics teachers identified three or four phases of the experimentation process. Finally, more than half of the physics teachers either identified two, one, or zero experimentation phases (31%) or left the item blank (21%).

Table 79. Descriptive Statistics of Teacher Responses to Item 11

	Correct	Partially correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)	n (%)
KIS.11	9 (11%)	34 (37%)	28 (31%)	19 (21%)	90 (100%)

The answer of PT 6 was classified as correct since he accurately identified the phases as determining the problem, controlled experiment, collecting data and analyzing data. The teacher also correctly wrote a hypothesis as "Aluminum conducts heat better". Several teachers either identified three or four experimentation phases correctly. For example, PT 26 could correctly identify four experimentation phases but not write an appropriate hypothesis. For this reason, his answer was classified as partially correct. In a similar vein, PT 6 could correctly identify four experimentation phases. However, she failed to identify the problem identification phase and wrote an irrelevant answer as "Determining the subject".

Answers of the physics teachers who correctly identified only two, one or zero experimentation phases were classified as false/irrelevant. For example, PT 61 identified no experimentation phase correctly. He incorrectly labeled the planning of the experiment phase as "Observation", the data collection phase as "Report" and the data analysis phase as again "Observation".

Each experimentation phase has a different correct answering rate. Most of the physics teachers could correctly identify planning of the experiment/experimentation phase (n=54) and analyze/interpret results phases (n=55). However, comparatively a smaller number of physics teachers correctly identified the data collection and problem identification phases. In fact, terms such as data collection and data analysis were not used very often by the physics teachers. In addition, only 37 teachers could write an appropriate hypothesis. For example, the

statement of PT 33 which is “Temperature change is proportional to specific heat” is ambiguous. Again, the statement of PT 71 which is “Aluminum is more affected by air temperature” is ambiguous and irrelevant.

Item 12 provides the physics teachers with solutions of two different students to a physics problem. The main difference between these students’ solutions was the use of units. The physics teachers were asked to interpret the advantages of using units while making calculations. The results of the analysis suggest that 62% of the physics teachers came up with relevant advantages of using units while making calculations (See Table 80). The 24% of the physics teachers gave irrelevant or unsophisticated answers and 11% of the physics teachers left the item blank.

Table 80. Descriptive Statistics of Teacher Responses to Item 12

	Correct	False/irrelevant	Blank	Total
	n (%)	n (%)	n (%)	n (%)
KIS.12	56 (62%)	24 (27%)	10 (11%)	90 (100%)

Most of the physics teachers stated advantages of using units such as “(Units) turn individual numbers into meaningful quantities that allow calculations” and “(Units) help to find errors while making calculations”. For example, PT 6 and PT 44 mentioned the importance of meaningful results whereas PT 17, PT 50, PT 20, and PT 54 mentioned the use of units as a check for errors (See Table 81).

A relatively low number of physics teachers gave irrelevant or less sophisticated answers (See Table 82). For example, PT 58 indicated that “It is good to do unit analysis. If the answers are requested in units in the answer key, (the student) will receive full credit.” This response illustrates a shallow understanding of the use of units while making calculations. In a similar vein, the answer of PT 43 is

just a description of the solution types of the two students and does not include any sophisticated interpretation regarding the use of units.

Table 81. Examples of Teacher Responses to Item 12 Classified as Correct

	Teacher responses
PT 6	"Using units produces meaningful results. The student understands the relationship between units."
PT 44	"It is useful to write the units because he will be aware if a different unit is used in the question. Eren knows which concept the result he found belongs to. However, Ali may think that the result of 200 points to any concept."
PT 17	"Solving questions by writing the units prevents mistakes. Concepts are not confused. If there is a unit conversion, it is not skipped. It provides a better understanding of the subject without memorization."
PT 50	"It reduces the percentage of miscalculations."
PT 20	"He/she reaches the last real unit by using the units. If the mass is given as kg in the question and the student does the calculation without making the necessary conversion, he/she cannot reach the joule. He/she makes a mistake."
PT 54	"Since he writes in units, there is less possibility of error in the result he finds."

Table 82. Examples of Teacher Responses to Item 12 Classified as False/Irrelevant

	Teacher responses
PT 58	"It is good to do unit analysis."
PT 43	"Eren goes into more detail, while Ali goes on a solution without even writing down the formula."

4.2 Results of the quantitative analysis

In this section, the results of quantitative analysis are presented. First, the results of the descriptive statistics are presented. Then, the results of the item analysis are illustrated. Specifically, results of item difficulty, item discrimination, item-total correlation, Cronbach's alpha and interrater reliability analysis are presented.

Table 83 presents descriptive statistics for each item. It illustrates each item's mean, standard deviation, minimum and maximum values and the total scores for each subscale. The mean value of the total score obtained from the whole instrument was 15.27 (SD=3.30).

Table 83. Descriptive Statistics for Each Item and Total Scores

	Mean	Std. Dev.	Min	Max		Mean	Std. Dev.	Min	Max
SU 1	1.1000	.45097	0	2	IS 1.a	.8000	.40224	0	1
SU 2	.7333	.44469	0	1	IS 1.b	.4778	.50230	0	1
SU 3	.8444	.36446	0	1	IS 2.a	.4556	.50081	0	1
SU 4	.5667	.49831	0	1	IS 2.b	.1778	.38447	0	1
SU 5	.3556	.48136	0	1	IS 3	.3222	.46995	0	1
SU 6	.4222	.49668	0	1	IS 4	.4889	.50268	0	1
SU 7	.9444	.23034	0	1	IS 5	.2111	.41038	0	1
SU 8	.7778	.41807	0	1	IS 6	.2921	.45732	0	1
SU 9	.2778	.45041	0	1	IS 7	.4778	.50230	0	1
SU 10	.6667	.73439	0	2	IS 8	.8333	.60429	0	2
SU 11	.7889	.41038	0	1	IS 9	.6667	.83464	0	2
SU 12	1.1667	.73820	0	2	IS 10	.2360	.42700	0	1
Total	8.6444	2.7450	2	13	IS 11	.5778	.67003	0	2
					IS 12	.6222	.48755	0	1
					Total	6.6333	3.3062	0	14

4.2.1 Item difficulty

Item difficulty index is defined as the proportion of students who correctly answer an item (Miller et al., 2009). Item difficulty is commonly calculated to infer whether a test reliably measures the intended ability (Bachman, 1990). The values of item difficulty can range between 0 to 1. Values closer to 0 indicate more difficult items whereas values closer to 1 indicate easier items. Item difficulty is calculated for each item of a test. Values between .2 and .8 are regarded as acceptable as a rule of thumb.

Item difficulty values of each item of the PCK test are presented in Table 84. The item difficulty values range from .19 to .94. One item has a difficulty value

below .2 and 2 items have a difficulty value above .8. The mean difficulty values of all items are calculated as .50.

Table 84. Item Difficulty Index of Each Item

Item	Item Difficulty	Item	Item Difficulty
KSU.1	.75	KIS.1a	.80
KSU.2	.73	KIS.1b	.49
KSU.3	.84	KIS.2a	.46
KSU.4	.50	KIS.2b	.19
KSU.5	.36	KIS.3	.32
KSU.6	.42	KIS.4	.49
KSU.7	.94	KIS.5	.21
KSU.8	.78	KIS.6	.29
KSU.9	.28	KIS.7	.48
KSU.10	.33	KIS.8	.42
KSU.11	.78	KIS.9	.34
KSU.12	.59	KIS.10	.23
		KIS.11	.29
		KIS.12	.62

The distribution of the item difficulty values is presented in Table 85. The table shows that 3.9% of the items have a difficulty value below .2 and 7.6% of the items have a difficulty value above .8. In total, 88.3% of the items have a difficulty value between .2 and .8. Specifically, 57.6% of the items have an item difficulty value between .2 and .5 and 30.7% of the items have an item difficulty value between .5 and .8.

Table 85. Distribution of the Item Difficulty Index

Difficulty indices	Frequency	Percentage	Quality
Below .2	1	3.9	Very difficult
.2-.5	15	57.6	Good
.5-.8	8	30.7	Best
Above .8	2	7.6	Very easy
Total	26	100	

Item 3 and Item 7 have the highest item difficulty values of the instrument. This implies that most physics teachers could correctly answer these items. Item 3 examines teachers' knowledge of the alternative conception of "84 °C is twice as high as 42 °C". This conception reveals a basic misunderstanding regarding the units of temperature. In a similar vein, Item 7 depicts an alternative conception of temperature. Specifically, a student conceptualized temperature as something transferrable, such as heat. These alternative conceptions may be regarded as more basic and general. Furthermore, these items did not request teachers to interpret the causes of wrong student statements or come up with possible wrong student answers. Thus, interpreting these alternative conceptions might have been easier for the teachers. The overall results also suggest that teachers had more difficulty in interpreting alternative conceptions of heat and internal energy compared to temperature.

Item 2.b has the lowest item difficulty value. This implies that most of the teachers' answers to this item were not correct. Item 2.a was multiple-choice and requested the physics teachers to choose the quantity which can be explained by the analogy specified in the item. Item 2.b, on the other hand, requested the physics teachers to interpret the limitations of the analogy further. Only less than half of the physics teachers could correctly answer Item 2.a and choose the physical quantity that can be explained by the analogy. Thus, it is plausible to expect that teachers who know an analogy might not necessarily know the limitations of the analogy. This might explain the low item difficulty value of Item 2.b.

4.2.2 Item discrimination

Item discrimination is used to assess whether items can differentiate between high-ability and low-ability participants (Miller et al., 2009). The values of item discrimination can range from -1 to 1. An item discrimination value of 1 indicates that the successful participants perform much better than the less successful participants on the item. On the contrary, an item discrimination value of -1 indicates that the less successful participants perform much better than the successful participants on the item. In this regard, item discrimination values are desired to be positive and not negative. Item discrimination is calculated for each item of a test. Values greater than .2 are considered as acceptable in differentiating participants with different abilities.

Item discrimination values of each item are presented in Table 86. All the item discrimination values are positive. The values range from .16 to .67. The average item discrimination value is .4. Only one item has a discrimination value below .2.

Table 86. Item Discrimination Index of Each Item

Item	Item Discrimination	Item	Item Discrimination
KSU.1	.25	KIS.1a	.33
KSU.2	.37	KIS.1b	.70
KSU.3	.29	KIS.2a	.54
KSU.4	.29	KIS.2b	.33
KSU.5	.33	KIS.3	.33
KSU.6	.58	KIS.4	.67
KSU.7	.20	KIS.5	.16
KSU.8	.25	KIS.6	.33
KSU.9	.38	KIS.7	.38
KSU.10	.44	KIS.8	.25
KSU.11	.38	KIS.9	.52
KSU.12	.67	KIS.10	.50
		KIS.11	.39
		KIS.12	.54

The distribution of the item discrimination values is presented in Table 87. Only 3.8% of the items have a discrimination value below .2 and 23% of the items have a discrimination value between .2 and .29. Most of the items (38.4%) have a discrimination value between .3 and .39 and 34.6% of the items have a discrimination value above .4.

Table 87. Distribution of the Item Discrimination Index

Discrimination indices	Frequency	Percentage	Quality
Below .2	1	3.8	Poor
.2-.29	6	23	Average
.3-.39	10	38.4	Good
Above .4	9	34,6	Excellent
Total	26	100	

Item 5 has a discrimination value below .2. This item requested the physics teachers to interpret why a classroom activity does not represent the characteristics of true experiments. The item discrimination value was .16 for this item. This implies that the item poorly discriminated between high and low performers of the teachers. The item difficulty value of the item also suggests that most of the teachers incorrectly answered the item.

4.2.3 Item-total correlation

An item-total correlation analysis was conducted to analyze the correlation between a score obtained from a specific item and the total score. Generally, a correlation coefficient above .2 is considered acceptable. The correlations between items and the total scale score were analyzed. Moreover, the correlations between items and total subscale scores were analyzed. Table 88 presents values of correlation coefficients

for each item. As can be seen from the Table, the correlation values range between .146 and .658, and Item 4 has a correlation value below .2.

Table 88. The Item-Total Correlation Coefficients of Each Item for the Whole Scale

Item	Item-total correlation	Item	Item-total correlation
SU 1	.352**	IS 1.a	.485**
SU 2	.398**	IS 1.b	.496**
SU 3	.286**	IS 2.a	.436**
SU 4	.146	IS 2.b	.401**
SU 5	.266*	IS 3	.310**
SU 6	.392**	IS 4	.512**
SU 7	.448**	IS 5	.205
SU 8	.332**	IS 6	.334**
SU 9	.325**	IS 7	.314**
SU 10	.496**	IS 8	.246**
SU 11	.391**	IS 9	.515**
SU 12	.658**	IS 10	.490**
		IS 11	.463**
		IS 12	.479**

The correlations between item and total subscale scores were also analyzed. The values of correlation coefficients are presented for each item in Table 89.

Table 89. The Item-Total Correlation Coefficients of Each Item for Each Subscale

Item	Item-total correlation	Item	Item-total correlation
SU 1	.456**	IS 1.a	.474**
SU 2	.455**	IS 1.b	.569**
SU 3	.438**	IS 2.a	.444**
SU 4	.338**	IS 2.b	.460**
SU 5	.411**	IS 3	.360**
SU 6	.457**	IS 4	.599**
SU 7	.448**	IS 5	.348**
SU 8	.430**	IS 6	.310**
SU 9	.381**	IS 7	.377**
SU 10	.531**	IS 8	.281**
SU 11	.481**	IS 9	.548**
SU 12	.734**	IS 10	.551**
		IS 11	.533**
		IS 12	.584**

4.2.4 Cronbach's Alpha coefficient

To measure the internal consistency of the test, Cronbach's alpha coefficient was calculated. The Cronbach's alpha coefficient for the Knowledge of Student Understanding section was $\alpha = .67$ and the Cronbach's alpha coefficient for the Knowledge of Instructional Strategies section was $\alpha = .70$. The Cronbach's alpha coefficient for the total test was $\alpha = .78$.

4.2.5 Interrater reliability

To calculate inter-rater reliability, 10% of the responses to the instrument were independently coded by two different researchers. The intraclass correlation analysis was conducted to investigate the interrater reliability. The results of the analysis indicate that the intraclass correlation coefficient was .94, indicating a perfect agreement between the coders.

4.2.6 The results of analysis after removing items

Several items did not satisfy the rule of thumbs for item difficulty and item discrimination values. Specifically, Item 3 and Item 7 of Knowledge of Student Understanding section and Item 2.b and Item 5 of Knowledge of Instructional Strategies were removed. After removing these items, the mean value of the total score obtained from the entire instrument became 13.10 (SD=4.79). The mean value of the total score obtained from the instrument's Knowledge of Student Understanding section became 6.86 (SD=2.50), and the mean value obtained from the Knowledge of Instructional Strategies section became 6.24 (SD=3.03). After removing the items, item-total correlation and Cronbach's alpha coefficient were

analyzed again. The new results of item-total correlations and Cronbach's alpha correlation were compatible with previous results and did not change dramatically.

CHAPTER 5

DISCUSSION

5.1 Overview of the study

PCK is one of the most important factors that influence teacher practice and student outcomes. In this regard, investigating PCK might contribute to efforts to enhance teacher learning, such as professional development programs and teacher education programs. One important characteristic of PCK is its topic-specific nature (Magnusson et al., 1999). PCK researchers suggest that teachers might have different levels of PCK for different topics, resulting in a need to investigate PCK for different topics (Barnett & Hodson, 2000). Thus, the topic of the written instrument was selected as heat and temperature in this study. Heat and temperature is one of the topics that students find difficult to learn (Harrison, Grayson & Treagust, 1999; Zacharia, Olympiou & Papaevripidou, 2008). A variety of alternative conceptions are frequently observed among students and even preservice and in-service teachers (Jasien & Oberem, 2002; Paik et al., 2007; Taqwa et al., 2019). A review of theliterature suggests that a very limited number of studies investigated PCK of heat and temperature and only for pre-service teachers. Thus, there is a need to examine in-service physics teachers' PCK by developing valid and reliable instruments. This study aimed to investigate in-service physics teachers' PCK of heat and temperature by developing a written instrument.

The development process of the instrument is informed by the work of Hill et al. (2004) and Hill et al. (2008) in the field of mathematics education. These researchers suggest an instrument development process to assess PCK with three steps: Conceptualization of the domain, development of initial items and field

testing. Moreover, the validity and reliability of the instrument are established by following the procedures of VASI and VNOS questionnaire development. These instruments are frequently used in the science education field. During the development process of VASI and VNOS questionnaires, Lederman et al. (2002) collected a variety of evidence to ensure the validity of the questionnaires. The researchers conducted cognitive interviews to ensure the cognitive validity of the instruments. Furthermore, evidence for construct validity was also collected by comparing scores of different groups of participants, namely experts and novices. In this regard, a similar approach was used in this study to ensure the validity of the instrument. By synthesizing the work done during the development process of two instruments, this study followed several steps to develop a written instrument. First the domain of PCK was conceptualized and initial items were developed. Then two rounds of cognitive interviews were conducted with physics teachers and teachers of other subjects. Based on the results of cognitive interviews and expert opinions, the written instrument was finalized and implemented to 90 in-service physics teachers. The answers of the physics teachers were coded based on a pre-developed rubric for each item.

The validity and reliability of the instrument were established by following several steps. The content validity of the instrument was ensured by taking expert opinions from two physics education professors. The items were sent to two physics education professors before administering the finalized version of the instrument. Two rounds of cognitive interviews were conducted to establish the cognitive validity of the instrument. The aim of conducting interviews was to investigate whether teachers use their PCK of heat and temperature or another kind of knowledge to solve the items. In other words, it was scrutinized whether the items

probed what was intended. During the cognitive interviews, the comprehensibility of the items was also analyzed by delving into the answers of the teachers. Items that do not elicit the use of intended knowledge or do not make sense were removed before the final implementation. The construct validity was established by conducting interviews with physics teachers as well as teachers of other subjects. One might expect that physics teachers perform better on a test measuring PCK of heat and temperature compared to preservice physics teachers and teachers of different subjects. Thus, items that differentiate physics teachers from teachers of different subjects were selected for the final implementation of the instrument.

The finalized version of the instrument was administered to 90 in-service physics teachers in İstanbul. A rubric that depicts false/irrelevant, correct, and/or partially correct responses for each item was developed. Teachers' responses were coded according to this rubric. Descriptive statistics was used to analyze data. The number and percentage of teachers for each code were calculated. To investigate the reliability of the instrument, the interrater reliability was calculated. Ten percent of the sample was independently coded by two trained researchers. The results of the intraclass correlation indicated a perfect agreement between the coders. Other statistical analyses such as item difficulty, item discrimination and item-total correlation were also conducted to analyze the items of the instrument. The results suggest that most of the items satisfy the rule of thumbs.

5.2 Evaluation of the results

In this research, a written instrument was developed and administered to in-service physics teachers to probe their PCK of heat and temperature. The instrument consisted of 24 items in the format of vignettes. Two dimensions of PCK named

Knowledge of Student Understanding and Knowledge of Instructional Strategies were examined. Teachers' answers to items were classified as false/irrelevant, correct and/or partially correct. For several items, most of the teachers' answers were classified as correct, whereas for several other items, most teachers' answers were classified as false/irrelevant.

Results of the analysis of the Knowledge of Student Understanding section revealed that teachers' answers belonged to different categories depending on the item. Most teachers were aware of students' difficulties of heat and temperature. However, most of the time, their interpretations of alternative conceptions were not sophisticated. For example, for Item 1, Item 10 and Item 12, only a small number of teachers' answers were classified as correct. In all three items, one of the alternative conceptions that teachers were expected to infer was "Substances possess heat." However, most of the teachers could not come up with this alternative conception. Most of the time, they tended to generalize the alternative conception with the statement of "Students cannot differentiate between heat and temperature." Although this statement reflects some understanding of student conceptions, it does not convey a deep interpretation of the reasons why the students think that way. In fact, confusion between heat and temperature might stem from other root alternative conceptions, such as "Substances possess heat." However, only a small number of teachers could correctly interpret the root cause of this difficulty as "Students think that matter can possess heat". This might indicate that the second group of teachers had more reflected about student difficulties and identified the root alternative conception. This finding is compatible with research studies suggesting that teachers tend to interpret student mistakes with general statements (Eroğlu & Tanışlı, 2015; You, 2006) and do not brainstorm about the possible causes of the mistakes (Arani et

al., 2017). Similarly, Kellner et al. (2011) called preservice science teachers' knowledge of student difficulties in differentiating between heat and temperature as an initial conception that should be developed.

Specifically, teachers were expected to infer three alternative conceptions in Item 1. Only 14% of the physics teachers could come up with three alternative conceptions. The remaining of them either inferred two or one alternative conception or simply stated that students confused heat and temperature. The answers of these teachers were classified as partially correct. Unlike the first item, Item 10 asked physics teachers the causes of why a student gives a wrong answer to a question. Thus, answers such as "Students confused heat and temperature" were classified as false/irrelevant since the statement does not reflect the core cause of the mistake. In other words, the teachers were asked why students in the vignette confused heat and temperature. Thus, simple answers that do not reflect the core alternative conception were classified as false/irrelevant. In a similar vein, a low number of teachers inferred the alternative conception of "Substances possess heat" in Item 12. Only 37% of the physics teachers inferred two alternative conceptions, and 43% of them inferred one alternative conception on the vignette in Item 12.

Most of the physics teachers' answers were classified as false/irrelevant on Item 5, Item 6 and Item 9. On Item 5, teachers were first expected to choose possible incorrect student answers given to a multiple-choice question. Then, they were expected to infer why students might give the wrong answer. The results indicate that one-fifth of the physics teachers chose the correct answer as an incorrect answer that students could give. Thus, one might interpret it as an indication of lower levels of content knowledge among these teachers. Only 36% of the physics teachers correctly answered the second section of the item and interpreted the alternative conception of

"When the same amount of heat is given to different substances, their final temperatures are the same". In a similar vein, the answers of more than half of the teachers were classified as false/irrelevant to Item 6. Most of the teachers could not infer the alternative conception of "Metals are conductors". In Item 9 about student conceptions of insulators, less than one-third of the teachers' answers were classified as false/Irrelevant. Most of the teachers could not infer the alternative conception of "Wool warms people".

In Knowledge of Student Understanding section, the physics teachers demonstrated the highest performance on Item 2, Item 3, Item 7, Item 8 and Item 11. Most of the physics teachers (74%) correctly inferred the alternative conception about the reasons for feeling cold while holding metals in Item 2. The alternative conception "Metals are colder" was correctly stated by almost 70% of the physics teachers. 5% of the physics teachers interpreted the situation slightly differently and came up with another alternative conception that explain the student understanding evident in the vignette ("Coldness passes from metal to Ahmet"). The physics teachers demonstrated the highest performance in inferring an alternative conception of temperature. 95% of the physics teachers correctly interpreted the alternative conception "Temperature transfers from cold to warm" in Item 7. In Item 8, most of the physics teachers correctly inferred alternative conceptions regarding heat transfer. Specifically, they interpreted the alternative conception of "Coldness passes from ice to lemonade". The physics teachers were expected to interpret an alternative conception of a basic definition of internal energy in Item 11. Similarly, a very high rate of physics teachers correctly interpreted the faulty way of student thinking presented on the vignette. However, it should be noted that the item requested physics teachers interpret student understanding of the basic conceptualization of

internal energy. Most of the physics teachers could not interpret the alternative conception of internal energy in Item 1. Moreover, one fifth of them could not correctly solve a question of internal energy in Item 5. As one of the teachers during cognitive interviews indicated, the time allocated to teach internal energy in the curriculum was comparatively limited. Similarly, teachers might spend less time in teaching conduction, insulation or ways of heat transfer compared to the big concepts of the topic such as heat and temperature. This might prevent teachers from engaging in classroom discussions and delving into the student understanding of varying concepts. As Lin and Chiu (2009) indicated, teachers were not aware of difficulties and mental models of low-achieving students and did not design their instruction according to the needs of these students. The researchers suggested that teachers should establish classroom environments in which low-achieving students' mental models are revealed and elicited for revision of their understanding.

Adopting a traditional orientation into science teaching might be another reason for the physics teachers' PCK levels of student understanding. Melo-Nino et al. (2015) indicated that physics teachers adopting a traditional science teaching approach tend to view student conceptions as something to be replaced rather than elicited. Thus, as these teachers in their study were teaching an abstract topic such as electricity, they view students as content receivers from the teacher. In this regard, they viewed efforts to elicit student understanding as a waste of time. Since they did not believe the importance of delving into student understanding, they did not develop a repertoire of student understanding and possess lower levels of PCK.

Data obtained from cognitive interviews and the implementation of the written instrument revealed that teachers themselves might possess alternative conceptions. For example, statements of several teachers indicated that they also

think of heat as something possessable. This result might give clues about these teachers' content knowledge. Similarly, the first section of Item 5 of the Knowledge of Student Understanding section probed teachers to choose the incorrect answers that students might give to a multiple-choice question. One-fifth of the teachers chose the correct answer as an incorrect answer that students might give. In other words, they themselves were not sure about the correct answer to the question. Thus, it can be concluded that their low performance in knowledge of student understanding might result from their lower levels of content knowledge. As indicated in the literature, pedagogical content knowledge is related to content knowledge (Großschedl et al., 2015; Kaya, 2009; Şen et al, 2022). In line with this, teachers' pedagogical content knowledge of heat and temperature was found to be related to their content knowledge (Garcia-Carmona, 2020).

Most of the teachers' responses to items eliciting their knowledge of instructional strategies were classified as false/irrelevant. The teachers demonstrated the highest performance in designing an experiment that addresses an alternative conception. However, their answers to items targeting knowledge of analogies and demonstrations were generally classified as false/irrelevant. Moreover, most of the teachers did not correctly differentiate activities from true experiments. Specifically, most teachers' answers belonged to false/irrelevant category for Item 2, Item 3, Item 5, Item 6 and Item 10. The first section of Item 2 requested the physics teachers to infer the physical quantity that can be explained by an analogy. Almost half of the teachers could come up with a correct answer. However, only a few teachers' answers were classified as correct when they were expected to interpret the limitations of the analogy. This finding is compatible with the findings of the study of Bergqvist et al. (2016). The researchers indicated that experienced chemistry

teachers were not aware of the limitations of models. Moreover, most of the teachers could not infer how representations might impede student understanding (Bergqvist et al., 2016).

Most teachers' answers to Item 3 were also classified as false/irrelevant or Blank. These teachers could not infer the topic-specific advantages of using simulations while conducting an experiment on heat equilibrium. They stated the advantages in general terms, which may be evaluated as an indicator of high pedagogical knowledge (PK) rather than pedagogical content knowledge (PCK). In other words, topic-specific references to the advantages of using simulations reflect more sophisticated pedagogical content knowledge. For example, several physics teachers stated the advantage of using simulations over real laboratory materials is that "Simulations give more accurate results." However, a comparatively low number of physics teachers indicated that "Using simulations prevents the influence of confounding variables such as heat loss." The second group of teachers made a topic-specific reference and thus demonstrated a more sophisticated PCK compared to the first group of teachers. This finding is similar to the findings of research studies indicating that even experienced teachers may consult on pedagogical knowledge rather than pedagogical content knowledge (Friedrichsen et al., 2009; Mansour, 2013).

Three items of the Knowledge of Instructional Strategies section aimed to elicit the knowledge of the controlled mechanism of the experiments. In Item 4, the physics teachers were requested to identify the error of a student who varied two variables at the same time in an experiment. Only half of the teachers could correctly interpret the student's mistake. Several teachers mentioned other confounding variables that might influence the results of the experiment although they could not

detect the main problematic aspect of the student's design of the experiment. In Item 5, teachers were requested to infer how a simple demonstration differs from a true experiment. The teachers were expected to mention the lack of controlled mechanisms in the demonstration. Again, most of the teachers could not come up with correct answers. In a similar vein, Item 10 requested the physics teachers to revise an activity to be more aligned with the nature of scientific experiment steps. The results suggest that almost three-fourth of the physics teachers could not come up with relevant suggestions.

Item 11 requested the physics teachers to infer each phase of an experimentation process. The teachers were expected to scrutinize scientific experimentation steps conducted in a classroom and label each of them. They were also expected to write a hypothesis. The results suggest that only half of the teachers' answers were correct and/or partially correct. The most correctly inferred steps were planning the experiment and analysis of the results phases. Most of the teachers could not infer data collection and problem identification phases. Again, less than half of the teachers did not write a correct hypothesis. This result may be related to teachers' insufficient use of experimentation in classes. As Mthethwa-Kunene et al. (2015) indicated secondary school science teachers did not use experimentation in classes to help students understand the concepts.

Item 7 and Item 8 aimed to elicit teachers' knowledge of demonstration. Item 7 depicted a demonstration in which food dye spreads faster in hot water compared to cold water. The teachers were requested to infer the aim of the demonstration. Almost half of the teachers could come up with a correct explanation whereas the remaining teachers could not give any relevant answers. Item 8, a closed-ended item, requested teachers to choose physical events that can be explained by the

demonstration. The aim of the demonstration was to visualize convection and teachers were expected to interpret physical events that were examples of convection. Only one third of the teachers could correctly identify more than half of the examples of convection.

In Knowledge of Instructional Strategies section, the physics teachers demonstrated the highest performance on Item 1.a and Item 12. Item 1.a requested the physics teachers to design an experiment that elicits a student alternative conception. Most of the teachers correctly designed an experiment that targets the alternative conception of "All metals have the same specific heat". The second section of the item requested physics teachers to provide reasonings about the importance of integrating student pre-knowledge into lessons. Several teachers provided relevant reasons such as the importance of doing by learning on changing alternative conceptions. However, more than half of the teachers' answers were classified as false/irrelevant for this item. They indicated irrelevant reasons about the importance of eliciting student preconceptions into lessons. Physics teachers' performance was relatively high on Item 12. More than half of the teachers (%62) made relevant interpretations of the advantages of using units while solving problems. "(Units) turn individual numbers into meaningful quantities" and "(Units) help to find errors" were the advantages cited most by the teachers.

In a related study, Akın and Uzuntiryaki-Kondakçi (2017) indicated that in-service teachers possess insufficient knowledge of subject-specific instructional strategies, and this might result from their didactic orientations to science teaching. The researchers indicated that teachers with didactic orientations tend to adopt a certain style of teaching without considering the specificities of the topics being taught. Thus, they might refrain from integrating suitable instructional strategies into

their teaching, which might reciprocally result in a lack of knowledge of instructional strategies. Similarly, Haney and McArthur (2002) indicated that teachers' implementation of instructional strategies is influenced by exam systems and curriculums of the countries. The concern to cover all the topics and the style of high-stakes tests were found to be influential on teachers' choice of instructional strategies. This might contribute to teachers' lack of performance on items assessing their knowledge of instructional strategies since teacher practice, and teacher knowledge correlate with each other (Jasien & Oberem, 2002; Paik et al., 2007). Teachers' lower levels of PCK of instructional strategies might also be related to the restricted time available to cover the content. In a related study, Melo Nino et al. (2015) indicated that physics teachers with lower levels of PCK of instructional strategies generally felt time pressure and tended to neglect practical work in their classes.

The physics teachers demonstrated higher performance for knowledge of student understanding compared to knowledge of instructional strategies. In other words, the percentages of teacher answers classified as correct or partially correct were higher for the KSU dimension in comparison to the KIS dimension. Teachers know several difficulties and alternative conceptions of students but demonstrated lower performance on items that target to assess their knowledge of instructional strategies. This finding is consistent with the results of several research studies that point out the different levels of knowledge of student understanding and knowledge of instructional strategies of teachers. Van Driel and Verloop (2022) indicated that teachers who have an awareness of student difficulties on a certain topic did still not use instructional strategies that target student difficulties. Similarly, Bergqwist

(2016) indicated that teachers' use of instructional strategies was insufficient and did not target student difficulties that even teachers were aware of.

The results of this study suggest that in-service physics teachers demonstrated insufficient knowledge of student understanding and instructional strategies for the topic of heat and temperature. This result is compatible with research findings indicating that in-service teachers have insufficient PCK of student understanding and instructional strategies (Mthethwa-Kunene et al., 2015; Melo-Nino et al.; 2015). Although they illustrated some form of understanding of student conceptions, their interpretations were often too general and did not delve into the core alternative conceptions. Most of the teachers did not make correct evaluations of student understanding of heat conduction. Although they correctly inferred erroneous ways of student thinking about the basic definition of internal energy, one-fifth of the physics teachers could not detect the correct answer to an intriguing question about internal energy. Most of the physics teachers' answers to items about knowledge of instructional strategies were also classified as false/irrelevant. The physics teachers demonstrated the highest performance in designing an experiment to elicit a wrong student idea and interpreting the advantages of using units while making calculations. However, most of the teachers gave insufficient answers to items targeting their knowledge of demonstrations, analogies, and characteristics of true experiments. They also could not give relevant answers to an item that probes the importance of integrating preconceptions into lesson plans. Cohen and Yarden (2008) indicated that both internal and external factors might contribute to the levels of teachers' PCK. For example, the way a teacher themselves learned a specific topic and their proficiency in subject matter might contribute to their own way of teaching as internal factors. The high-stakes testing in a country might contribute as an

external factor to teachers' PCK. Cohen and Yarden (2008) indicated that national evaluation systems were found to be influential on what teachers prefer to focus on their instruction.

5.3 Implications

This study aimed to develop a vignette-based instrument to probe in-service physics teachers' PCK of heat and temperature. The cognitive interviews, comparing scores between physics and non-physics teachers, and item analysis results support the validity and reliability of the instrument. Thus, the instrument can be used to probe PCK of different samples of in-service physics teachers or analyze the interrelationships between PCK and other teacher or student-related constructs. Moreover, similar instruments can be developed for other topics. These instruments can be used in examinations of teacher qualification.

The results of this study suggest that in-service physics teachers' PCK of heat and temperature was not at the desired level. Physics teachers were aware of several student alternative conceptions of heat and temperature. However, their interpretations were mostly general and did not delve into the depth of student understanding. Similarly, a considerably low number of teachers' answers were classified as Correct to items probing their knowledge of instructional strategies. In this regard, the findings of this study have some implications for science education researchers, curriculum developers and policymakers. Akın and Uzuntiryaki-Kondakçı (2017) indicated that making PCK explicit in science education courses may contribute to the effective development of PCK. In other words, pre-service teachers should be introduced to the nature and components of PCK during their courses. The researchers indicated that by using knowledge of PCK, pre-service

teachers could more efficiently develop their PCK in practical courses. Enabling pre-service teachers to reflect on their practice as well as weak and strong components of their PCK might also contribute to the development of PCK in pre-service as well as in-service years (Lin, 2010; Akın & Uzuntiryaki-Kondakçı, 2017).

The findings of this study also have several implications for in-service education programs. Professional development programs that target teachers' knowledge of student understanding and instructional strategies could help the development of PCK of the teachers (Mthethwa-Kunene et al., 2015; Akın & Uzuntiryaki-Kondakçı, 2017; Bergqvist et al, 2016). Effective professional development programs have several characteristics such as enduring a sufficient amount of time, emphasizing active learning, aligning to the curriculum, and promoting collaboration among the participants (Desimone, 2009). Several professional development programs were found to be effective on science teachers' PCK (Roth et al., 2011; Johnson & Cotterman, 2015). For example, Roth et al. (2011) investigated the influence of a video-based professional development program in which teachers watch and reflect videos of classroom instruction in a community of practice. The results suggest that science teachers enhanced their PCK. Thus, professional development programs that target to enhance in-service physics teachers' PCK of heat and temperature might yield positive outcomes.

In this regard, teachers should be provided with opportunities to explore, reflect, and discuss student understanding of specific topics. They should also be provided with opportunities to enhance their instructional repertoire with various strategies to best address student understanding. They might review literature, collect data from their own classrooms about student ideas, explore different demonstrations, illustrations and analogies and engage in hands-on activities. In this

way, they might turn their general interpretations of student understanding such as "Students could not differentiate heat and temperature" into more sophisticated ones. Their orientations to teaching might also be elicited and turned into more student-centered ones during these programs. Moreover, teachers' content knowledge can also be targeted with these programs. Their alternative conceptions could be elicited and turned into scientific ones.

Teachers might also have an opportunity to develop their PCK through educative curriculum materials. Educative curriculum materials have been found effective on teachers' professional knowledge (Davis & Krajcik, 2005). Teachers could be provided with curriculum materials that stress students' alternative conceptions and preconceptions in different topics. Furthermore, instructional strategies eliciting student conceptions might also be embedded in these materials to enhance physics teachers' PCK of specific topics.

5.4 Recommendations for future research

This study examined in-service physics teachers' PCK of heat and temperature for two dimensions: Knowledge of student understanding and knowledge of instructional strategies. In a study in which Park and Chen (2012) mapped out the interrelations between the dimensions of PCK, it was found that the connection between knowledge of student understanding and knowledge of instructional strategies was the predictor of the coherence of the knowledge structure of the teachers. Thus, as with many other studies in literature, this study focused on these two dimensions. However, PCK has other dimensions such as orientations to science teaching, knowledge of assessment and knowledge of curriculum. Other studies

might integrate these dimensions into efforts to examine teachers' PCK of heat and temperature.

Teachers' PCK was found to be related to numerous outcomes, such as teacher practice and student outcomes. Future studies may investigate the interrelations between PCK and classroom practice as well as student outcomes such as understanding, motivation, and self-efficacy. Moreover, PCK is topic-specific, and teachers may have different levels of PCK for different topics of a subject. In this study, teachers' PCK of heat and temperature was examined by developing a written instrument consisting of vignettes. Future studies may develop different instruments to probe teachers' PCK of other topics. Apart from examining teachers' PCK, investigating other constructs such as beliefs and their relationship to PCK as well as teacher practice is also of importance. Thus, future studies might gather information and develop valid and reliable measures to investigate the amplifiers as well as their interrelations to PCK and teacher practice. In this study, cognitive interviews and written instruments were used to illuminate teachers' PCK of heat and temperature. Other data collection methods such as observations could be used in further studies to investigate how teachers' PCK is revealed in classroom practice.

This study was conducted with in-service physics teachers working in diverse regions of İstanbul. Although İstanbul is the largest city in the country in terms of population, participants were from only one city of the country. Future studies might increase the number of participants as well as the variety of the cities.

5.5 Limitations

This study has several limitations. Cognitive interviews and a written instrument were used as data sources in this study. Cognitive interviews were conducted to

investigate whether teachers understood the items as intended. Furthermore, the knowledge bases the teachers used to solve the items were also examined. These interviews were conducted with a comparatively low number of participants. In other words, cognitive interviews were not conducted with teachers who participated in the final implementation of the written instrument. Although the first and second rounds of cognitive interviews establish evidence regarding the comprehensibility of the items, there is a possibility that teachers who filled out the written questionnaire might not understand the items as intended. Thus, there remains a likelihood that the items might not fully elicit teachers' knowledge.

Another limitation of the study is the limited number of PCK dimensions that the study focused on. The PCK consists of multiple dimensions, and only two dimensions (knowledge of student understanding and knowledge of instructional strategies) were addressed in this study. Although these dimensions were the most investigated in literature, examining other dimensions would have given a more complete picture of teachers' PCK. The results of item analysis also revealed that some items did not satisfy the rule of thumbs. These items should be cautiously evaluated in other implementations and controlled whether they work in other samples.

The final limitation of the study is about the implementation of the written instruments. During data collection, the teachers were visited in their schools and given the instrument. Most of the time, the teachers had not enough time to fill out the instruments at school and took them to their homes. The teachers were expected to sincerely give answers on their own. For this reason, the use of the internet, textbooks, or other sources to answer the items could not be controlled.

APPENDIX A

DEFINITION OF IMPORTANT TERMS

Term	Definition
Pedagogical content knowledge (PCK)	A special form of teacher professional knowledge that combines content and pedagogy to prepare instruction that meets needs of learners with various interests (Schulman, 1987).
Knowledge of student understanding	Teachers' knowledge of concepts that are hard for students to learn and that students perceive as difficult, the prerequisite knowledge for learning a particular topic, and an awareness of differences in students' approaches to learning (Magnusson et al., 1999; Gess-Newsome, 2015).
Knowledge of instructional strategies	Teachers' knowledge of particular strategies and methods such as activities, demonstrations and representations to help students understand a specific science topic (Magnusson et al., 1999).
Cognitive interviews	Interviews that are conducted for the purpose of examining how participants perceive, process and respond to instrument items (Padilla & Leighton, 2017).
Vignette	Authentic descriptions of teaching situations (Brovelli et al., 2014).
Classification schema	A rubric that represents as many examples as possible of answers to vignettes and classification of these answers as correct, partially correct or false/irrelevant.
Subject of teaching	Teachers' subject of their teaching such as physics, chemistry or Turkish education.
Degree of teachers	Teachers' degree of teaching such as being a pre-service or in-service teacher.

APPENDIX B

REVIEW ARTICLES

Code	Article reference
1	Davidowitz, B., & Potgieter, M. (2016). Use of the Rasch measurement model to explore the relationship between content knowledge and topic-specific pedagogical content knowledge for organic chemistry. *International Journal of Science Education*, *38*(9), 1483-1503.
2	Ergönenç, J., Neumann, K., & Fischer, H. E. (2014). The impact of pedagogical content knowledge on cognitive activation and student learning. *Quality of Instruction in Physics*, 145-160.
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4	Großschedl, J., Harms, U., Kleickmann, T., & Glowinski, I. (2015). Preservice biology teachers' professional knowledge: Structure and learning opportunities. *Journal of Science Teacher Education*, *26*(3), 291-318.
5	Großschedl, J., Welter, V., & Harms, U. (2019). A new instrument for measuring pre- service biology teachers' pedagogical content knowledge: The PCK- IBI. *Journal of Research in Science Teaching*, *56*(4), 402-439.
6	Joachim, C., Hammann, M., Carstensen, C. H., & Bögeholz, S. (2020). Modeling and measuring pre-service teachers' assessment literacy regarding experimentation competences in biology. *Education Sciences*, *10*(5), 140.
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11	Mahler, D., Großschedl, J., & Harms, U. (2017). Using doubly latent multilevel analysis to elucidate relationships between science teachers' professional knowledge and students' performance. *International Journal of Science Education*, *39*(2), 213-237.
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14	McNeill, K. L., González- Howard, M., Katsh- Singer, R., & Loper, S. (2016). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high- quality PCK rather than pseudoargumentation. *Journal of Research in Science Teaching*, *53*(2), 261-290.
15	Meschede, N., Fiebranz, A., Möller, K., & Steffensky, M. (2017). Teachers' professional vision, pedagogical content knowledge and beliefs: On its relation and differences between pre-service and in-service teachers. *Teaching and Teacher Education, 66*, 158-170.
16	Monet, J. A., & Etkina, E. (2008). Fostering self-reflection and meaningful learning: Earth science professional development for middle school science teachers. *Journal of Science Teacher Education*, *19*(5), 455-475.
17	Prasetyo, Z. K. (2019). The implementation of mentoring based learning to improve pedagogical knowledge of prospective teachers. *International Journal of Instruction*, *12*(3).
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22	Sorge, S., Kröger, J., Petersen, S., & Neumann, K. (2017). Structure and development of pre-service physics teachers' professional knowledge. *International Journal of Science Education*, *41*(7), 862-889.
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25	Cohen, R., & Yarden, A. (2009). Experienced junior-high-school teachers' PCK in light of a curriculum change: "The cell is to be studied longitudinally". *Research in Science Education*, *39*, 131-155.
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31	Melo, L., Cañada, F., & Mellado, V. (2017). Exploring the emotions in Pedagogical Content Knowledge about the electric field. *International Journal of Science Education*, *39*(8), 1025-1044.
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APPENDIX C

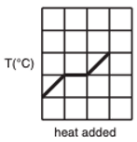
PRELIMINARY ITEMS

Knowledge of student understanding

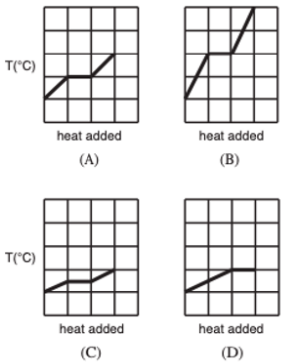
KSU.1

Teacher Ayşe asked the following question in a physics exam.

The heat-temperature graph of a certain amount of water which is given heat is as follows:



When the same amount of heat is given to water whose mass is doubled, what will the heat-temperature graph of water look like?



List the incorrect answers students can give to this question. State the misconceptions/difficulties that caused students to choose the wrong option.

Classification	Criteria
Correct (1)	Options A, B and C are chosen AND One or more of the following answers are given: • The amount of a substance given heat does not affect the rate of temperature change. • The melting temperature of a substance depends on its amount/is not constant. • The student constructed a wrong ratio mathematically.
False/Irrelevant (0)	• An incorrect or irrelevant option is chosen.
Blank (0)	• The question was left unanswered.

KSU.2

A physics teacher asked his students the following question.

There is 100 g of water in container A and 200 g of water in container B. The water in the containers is initially at room temperature. Afterwards, the water in container A was heated to 75 C and the water in container B to 50 C until the heated water reaches room temperature again. Which container had more heat flow?



List the incorrect answers students can give to this question. Also indicate any misconceptions/difficulties that may cause students to give incorrect answers.

Classification	Criteria
Correct (1)	One of the following answers is given: • Substances with greater mass have higher heat. / Substances with greater mass always transfer more heat. • Substances with higher temperatures have more heat. / Substances with higher temperatures always transfer more heat.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.3

In a physics lesson, the teacher asks her students the following question:

A student goes to the sea on a very hot summer day. He fills a bucket with sea water and measures its temperature as 16 degrees. The student also directly measures the temperature of sea water as 16 degrees with the same thermometer. As a result of his measurements, the student makes the following inference: "Since both water sources are at the same temperature, the heat energy they have is equal." Do you agree with the student's inference?

Seventy-five percent of the students answer "yes" to this question.

Write the misconception that caused the students to give this answer.

Classification	Criteria
Correct (1)	One of the following answers is given: • Heat is one of the internal properties of matter. • Substances possess heat.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.4

Teacher Emre drew the following table on the blackboard during a class discussion.

	A	B
Mass	2 g	25 g
Specific heat	$4.0 \frac{J}{°C \times g}$	$2.0 \frac{J}{°C \times g}$
Temperature	30 °C	30 °C

The teacher asked, "What happens if substances A and B come together in a thermally insulated environment?" and requests the students to discuss.

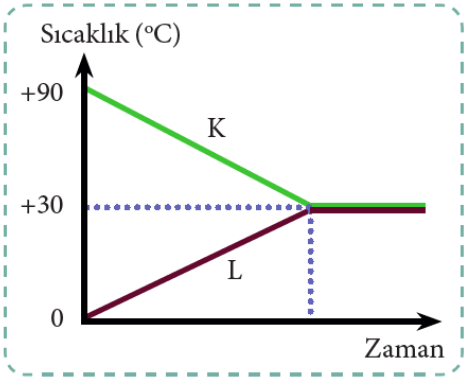
Which of the following is one of the wrong answers that students can give to this question? (You can mark more than one)

A. Heat flow is from B to A because B has more mass. (x)
B. Heat flow is from A to B because A has more specific heat. (x)
C. Heat flow is from A to B because each gram of A has more heat. (x)
D. Heat flow is from B to A because B has more internal energy. (x)
E. There is no heat flow.

Classification	Criteria
Correct (1)	One, some or all of the options A, B, C or D are selected. AND Option E is not selected.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

KSU.5

A physics teacher asks her students to interpret the graph in the figure.



One of the students commented as follows: “Initially, the heat of object K is higher than the heat of object L. Since the heat of body K is higher, its internal energy is higher than L. Over time, there was a temperature transition from K to L, the temperature of K decreased and the temperature of L increased."

Which of the following is one of the misconceptions that stand out in the student's comments? (You can mark more than one).

A. Substances possess heat. (x)
B. Internal energy is a measure of the total heat of a substance. (x)
C. Temperature is a quantity that can be transmitted. (x)
D. Heating a substance always increases its temperature.

Classification	Criteria
Correct (2)	All three options of A, B and C are chosen.
Partially correct (1)	Two of the options of A, B and C are chosen.
False/ irrelevant (0)	One of the options of A, B and C is chosen.
Blank (0)	The question was left unanswered.

KSU.6

Teacher Ayşe shares the following text with his students while teaching the topic of internal energy.

Internal energy of an ice block at sea level and is greater than the internal energy of a jug full of boiling water in the same environment.

The teacher asks the students to think about and discuss the reasons for this situation.

Mark any incorrect explanations that students may make during the discussion (you can mark more than one).

A. The heat of ice is greater than the heat of water. (X)
B. The mass of ice is greater than the mass of water.
C. The temperature of ice is greater than the temperature of water. (X)
D. The average kinetic energy of ice molecules is greater than the average kinetic energy of water molecules. (X)

Classification	Criteria
Correct (1)	One, some or all of the options A, C or D are selected.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

KSU.7

A physics teacher will explain internal energy to his students.

Which of the following quantities is preliminary information that can be mentioned for students to understand the concept of internal energy? (You can mark more than one).

A. Power
B. Conductivity
C. Kinetic energy
D. Potential energy
E. Gravitational force

Classification	Criteria
Correct (1)	All options of C, D and E are selected
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

Knowledge of instructional strategies

KIS.1

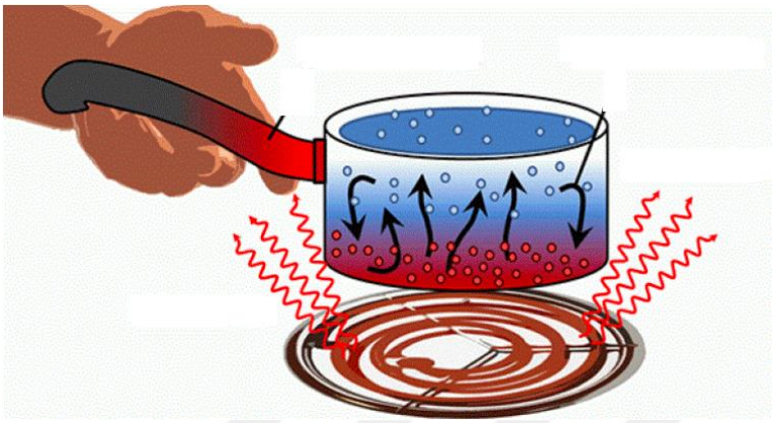
Teacher Pelin wants to show that the temperature change in substances that exchange heat depends on the mass of those substances. In line with this purpose of the lesson, students will conduct experiments in groups. Which of the following material lists would be appropriate for teacher Ayşe to use for this purpose? (You can choose more than one)

Material list	Material list	Material list	Material list
-250 gr.oil -100 gr. oil -heater -thermometer -beaker	-100 gr. water -250 gr. oil -heater -thermometer -beaker	-100 gr. water -100 gr. oil -heater -thermometer -beaker	-100 gr. water -250 gr. water -heater -thermometer -beaker
1	2	3	4

	Appropriate	Not appropriate
Material list 1	+	
Material list 2		+
Material list 3		+
Material list 4	+	

KIS.2

Teacher Emre used the following illustration in a lesson where he taught the heat and temperature unit.



List the concepts/information that teacher Emre aims for the students to learn by using this representation.

Classification	Criteria
Correct (2)	Three of the following answers are given: • Energy transmission ways (Conduction, convection, radiation)
Partially correct (1)	Two of the following answers are given: • Energy transmission ways (Conduction, convection, radiation)
False/ irrelevant (0)	One of the following answers are given: • Energy transmission pathways (Conduction, convection, radiation) OR An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KIS.3

A physics teacher used the following analogy in his heat-temperature lesson: “To pop corn, corn kernels are added to a pot and placed on the stove. As time passes, the corn grains begin to move in the pot.”

Which of the following magnitudes can be explained by using this analogy?

A. Heat
B. Temperature (X)
C. Specific heat
D. Heat capacity

Classification	Criteria
Correct (1)	Option B is chosen.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

KIS.4

A physics teacher used the following analogy in his heat and temperature lesson: “Workers stack sandbags on top of each other and build a wall. Some workers are tougher than others. In other words, it can carry sandbags and create walls for a long time without getting too tired. Some workers can work very fast. But just because they work fast doesn't mean they can work for long periods of time.”

In the analogy he used, the physics teacher likened the wall made of sandbags to "transferred heat". Which of the following could be the other quantities simulated in this example?

Specific heat-Internal energy	
Heat capacity-Internal energy	
Internal energy-conductivity	
Heat capacity- conductivity	+

Classification	Criteria
Correct (1)	Only the “Heat capacity-Conductivity” option is selected.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

KIS.5

A physics teacher shows a demonstration in the lesson (Figure). The materials the teacher uses during the demonstration are as follows: Blue ice (colored with food coloring), red food coloring, plastic container, water.



Figure

What could be the main purpose of this activity? / What could be the reason for teacher Ayşe to do this activity?

Classification	Criteria
Correct (1)	One of the following answers is given: • Visualizing convection currents • Having students observe convection • Showing that heat flow is from hot to cold
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KIS.6

Teacher Ayşe will use an analogy in a lesson on heat flow. She sets up the mechanism in the figure to show that heat movement is from high temperature to low temperature and continues until the temperatures equalize. The tube with a large amount of water represents high temperature, and the tube with a small amount of water represents low temperature. When the passage between the tubes is released, the liquid level in the two tubes equalizes. With this demonstration, teacher Ayşe showed her students that the temperatures of objects are equalized as a result of heat exchange.



Şekil 1



Şekil 2

Write a misconception that this representation may cause in students.

Classification	Criteria
Correct (1)	The following answer is given: • Heat is a substance like a liquid.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

APPENDIX D

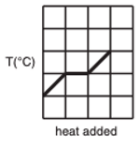
TURKISH VERSION OF THE PRELIMINARY ITEMS

Öğrenci anlayışları bilgisi

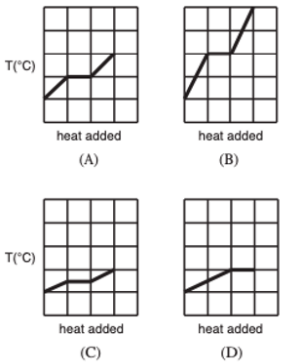
KSU.1

Ayşe öğretmen bir fizik sınavında aşağıdaki soruyu sormuştur.

Isı verilen belirli bir miktarda suyun ısı-sıcaklık grafiği aşağıdaki gibidir.



Aynı miktarda ısı, kütlesi iki katına çıkarılan suya verildiğinde suyun ısı sıcaklık grafiği nasıl olur?



Öğrencilerin bu soruya verebileceği yanlış cevapları listeleyiniz. Öğrencilerin yanlış şıkkı seçmelerine sebep olan yanılgılı düşünceleri/zorlukları belirtiniz.

Kodlama	Kriter
Doğru (1)	A, B ve C şıkları söylenir VE Aşağıdaki cevaplardan biri veya birkaçı verilir: • Isı verilen bir maddenin miktarı, sıcaklık değişim hızını etkilemez. • Bir maddenin erime sıcaklığı, miktarına bağlıdır/sabit değildir. • Öğrenci matematiksel olarak yanlış oran kurmuştur.
Yanlış/İlgisiz (0)	• Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	• Soru cevapsız bırakıldı.

KSU.2

Bir fizik öğretmeni, öğrencilerine aşağıdaki soruyu sormuştur.

A kabında 100 g, B kabında ise 200 g su bulunmaktadır. Kaplardaki sular başlangıçta oda sıcaklığındadır. Sonrasında, A kabındaki su 75 C ve B kabındaki su 50 C olana kadar ısıtılmıştır. Isıtılan sular tekrar oda sıcaklığına gelene kadar bekletildiğine göre hangi kaptan daha çok ısı akışı olmuştur?



Öğrencilerin bu soruya verebilecekleri yanlış cevapları listeleyiniz. Öğrencilerin yanlış cevap vermesine neden olabilecek yanılgılı düşünceleri/zorlukları da belirtiniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Kütlesi büyük olan maddelerin ısısı daha fazladır. / Kütlesi büyük olan maddeler her zaman daha çok ısı transfer eder. • Sıcaklığı büyük olan maddelerin ısısı daha fazladır. / Sıcaklığı büyük olan maddeler her zaman daha çok ısı transfer eder.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.3

Bir fizik dersinde, öğretmen öğrencilerine aşağıdaki soruyu sorar:

Bir öğrenci, çok sıcak bir yaz gününde denize gider. Bir kovaya deniz suyu doldurur ve sıcaklığını 16 derece olarak ölçer. Öğrenci, aynı termometreyle direkt deniz suyunun sıcaklığını da 16 derece olarak ölçer. Öğrenci, ölçümleri sonucunda şu çıkarımda bulunur: "İki su kaynağı da aynı sıcaklıkta olduğu için sahip oldukları ısı enerjisi eşittir". Öğrencinin yaptığı çıkarıma katılıyor musunuz?

Öğretmenin öğrencilerinin %75'i bu soruya "evet" cevabı verir.

Öğrencilerin bu cevabı vermelerine neden olan yanılgıyı/düşünceyi yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Isı maddenin içsel özelliklerinden biridir. • Maddelerin ısısı vardır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.4

Emre öğretmen, bir sınıf tartışması sırasında aşağıdaki tabloyu tahtaya çizmiştir.

Madde	A	B
Kütle	2 g	25 g
Öz ısı	$4.0\frac{J}{°C \times g}$	$2.0\frac{J}{°C \times g}$
Sıcaklık	30 °C	30 °C

Öğretmen "A ve B maddeleri ısıca yalıtılmış bir ortamda yan yana gelirse ne olur?" sorusunu sorar ve öğrencilerin tartışmasını ister.

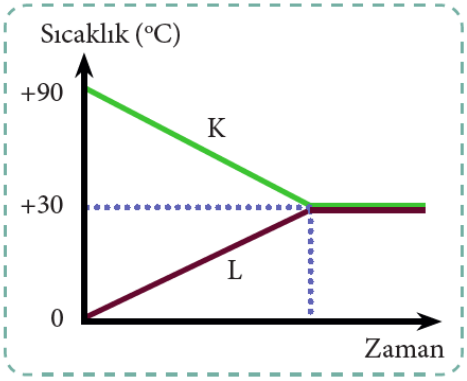
Aşağıdakilerden hangisi öğrencilerin bu soruya verebileceği yanlış cevaplardan biridir? (Birden fazla işaretleme yapabilirsiniz)

A. Isı akışı B'den A'ya doğrudur çünkü B'nin kütlesi daha fazladır. (X)
B. Isı akışı A'dan B'ye doğrudur çünkü A'nın öz ısısı daha fazladır. (X)
C. Isı akışı A'dan B'ye doğrudur çünkü A'nın her bir gramının ısısı daha fazladır. (X)
D. Isı akışı B'den A'ya doğrudur çünkü B'nin iç enerjisi daha fazladır. (X)
E. Isı akışı olmaz.

Kodlama	Kriter
Doğru (1)	A, B, C ya da D şıklarından bir, birkaçı ya da tamamı seçilir. VE E şıkkı seçilmez.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.5

Bir fizik öğretmeni, öğrencilerinden şekildeki grafiği yorumlamasını ister.



Öğrencilerden biri şu yorumda bulunur: "Başlangıçta K cisminin ısısı, L cisminin ısısından daha fazladır. K cisminin ısısı daha fazla olduğu için iç enerjisi de L'den daha yüksektir. Zaman içerisinde K'dan L'ye sıcaklık geçişi olmuş, K'nın sıcaklığı düşmüş ve L'nin sıcaklığı yükselmiştir."

Aşağıdakilerden hangisi öğrencinin yorumunda dikkat çeken yanılgılı düşüncelerdendir? (Birden fazla işaretleme yapabilirsiniz).

A. Maddelerin ısısı vardır. (X)
B. İç enerji bir maddenin toplam ısısının ölçüsüdür. (X)
C. Sıcaklık iletilebilen bir büyüklüktür. (X)
D. Bir maddeyi ısıtmak her durumda sıcaklığını artırır.

Kodlama	Kriter
Doğru (2)	A, B ve C şıklarından üçü seçilir.
Partially correct (1)	A, B ve C şıklarından ikisi seçilir.
Yanlış/İlgisiz (0)	A, B ve C şıklarından birisi seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.6

Ayşe öğretmen, iç enerji konusunu işlediği sırada öğrencileriyle aşağıdaki metni paylaşır.

Deniz seviyesinde ve aynı ortamda bulunan bir buz kalıbının iç enerjisinin, bir sürahi dolusu kaynar suyun iç enerjisinden daha büyük olduğu tespit edilmiştir.

Öğretmen öğrencilerden bu durumun sebepleri üzerinde düşünmelerini ve tartışmalarını ister.

Öğrencilerin tartışma sırasında ortaya atabilecekleri yanlış açıklamaları işaretleyiniz (Birden fazla işaretleme yapabilirsiniz).

A. Buzun ısısı suyun ısısından büyüktür. (X)
B. Buzun kütlesi suyun kütlesinden büyüktür.
C. Buzun sıcaklığı, suyun sıcaklığından büyüktür. (X)
D. Buz moleküllerinin ortalama kinetik enerjisi, su moleküllerinin ortalama kinetik enerjisinden büyüktür. (X)

Kodlama	Kriter
Doğru (1)	A, C ya da D şıklarından bir, birkaçı ya da tamamı seçilir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.7

Bir fizik öğretmeni, öğrencilerine iç enerji konusunu anlatacaktır.

Aşağıdaki büyüklüklerden hangisi öğrencilerin iç enerji kavramanı anlamaları için değinilebilecek ön bilgilerdendir? (Birden fazla işaretleme yapabilirsiniz).

A. Güç
B. İletkenlik
C. Kinetik enerji
D. Potansiyel enerji
E. Çekim kuvveti

Kodlama	Kriter
Doğru (1)	C, D ve E şıklarının tamamı seçilir
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğretim Yöntemleri Bilgisi

KIS.1

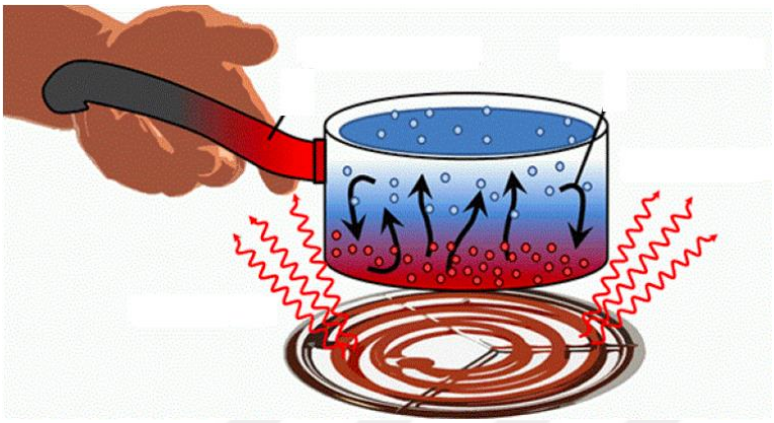
Pelin öğretmen, ısı alışverişi yapan maddelerde gerçekleşen sıcaklık değişiminin, o maddelerin kütlesine bağlı olduğunu göstermek istemektedir. Dersin bu amacı doğrultusunda çocuklar gruplar halinde deney yapacaktır. Ayşe öğretmenin bu amaç için aşağıdaki malzeme listelerinden hangilerini kullanması uygun olur? (Birden fazla seçim yapabilirsiniz)

MALZEME LİSTESİ	MALZEME LİSTESİ	MALZEME LİSTESİ	MALZEME LİSTESİ
-250 gr. Zeytinyağı -100 gr. Zeytinyağı -ısıtıcı -termometre -beher -maşa	-100 gr. Su -250 gr. Zeytinyağı -ısıtıcı -termometre -beher -maşa	-100 gr. Su -100 gr. Zeytinyağı -ısıtıcı -termometre -beher -maşa	-100 gr. Su -250 gr. Su -ısıtıcı -termometre -beher -maşa
1	2	3	4

	Uygun olur	Uygun olmaz
Malzeme listesi 1	+	
Malzeme listesi 2		+
Malzeme listesi 3		+
Malzeme listesi 4	+	

KIS.2

Emre öğretmen, ısı ve sıcaklık ünitesini işlediği bir derste aşağıdaki gösterimi kullanmıştır.



Emre öğretmenin, bu gösterimi kullanarak öğrencilerin öğrenmesini hedeflediği kavramları/bilgileri listeleyiniz.

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevaplardan üçü verilir: • Enerji iletim yolları (Kondüksiyon, konveksiyon, radyasyon)
Kısmen doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Enerji iletim yolları (Kondüksiyon, konveksiyon, radyasyon)
Yanlış/İlgisiz (0)	Aşağıdaki cevaplardan birisi verilir: • Enerji iletim yolları (Kondüksiyon, konveksiyon, radyasyon) YA DA Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KIS.3

Bir fizik öğretmeni ısı-sıcaklık dersinde şu analojiyi kullanmıştır: “Mısır patlatmak için bir tencereye mısır taneleri eklenir ve ocağın üstüne konulur. Süre geçtikçe mısır taneleri tencere içinde hareket etmeye başlar.”

Bu analoji aşağıdakilerden hangi büyüklüğü açıklamak için kullanılmış olabilir?

A. Isı
B. Sıcaklık (X)
C. Öz ısı
D. Isı sığası

Kodlama	Kriter
Doğru (1)	B şıkkı seçilir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KIS.4

Bir fizik öğretmeni ısı sıcaklık dersinde şu analojiyi kullanmıştır: “İşçiler, kum torbalarını üst üste dizip bir duvar yaparlar. Bazı işçiler diğerlerinden daha dayanıklıdır. Yani çok fazla yorulmadan uzun bir süre boyunca kum torbalarını taşıyıp duvar oluşturabilir. Bir kısım işçi ise çok hızlı çalışabilir. Fakat hızlı çalışıyor olmaları, uzun süre boyunca çalışabildikleri anlamına gelmez.”

Fizik öğretmeni, kullandığı analojide kum torbalarından oluşan duvarı “tranfer edilen ısı”ya benzetmiştir. Bu örnekte benzetimi yapılan diğer büyüklükler aşağıdakilerden hangisi olabilir?

Öz ısı-İç enerji	
Isı sığası-İç enerji	
İç enerji-İletkenlik	
Isı sığası-İletkenlik	+

Kodlama	Kriter
Doğru (1)	Yalnızca “Isı sığası-İletkenlik” seçeneği işaretlenir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KIS.5

Bir fizik öğretmeni, derste Şekil 1'deki gibi bir gösterimde bulunur. Öğretmenin gösterim sırasında kullandığı malzemeler şu şekildedir: Mavi buz (gıda boyasıyla renklendirilmiş), kırmızı gıda boyası, plastik kap, su



Şekil 1

Bu aktivitenin temel amacı ne olabilir? / Ayşe öğretmenin bu aktiviteyi yapma sebebi ne olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Konveksiyon akımlarını görselleştirmek • Öğrencilerin konveksiyonu gözlemlemesini sağlamak • Isı akışının sıcaktan soğuğa doğru olduğunu göstermek
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KIS.6

Ayşe öğretmen, ısı akışını işlediği bir derste bir analoji kullanacaktır (Şekil). Isı hareketinin yüksek sıcaklıktan düşük sıcaklığa doğru olduğunu ve sıcaklıklar eşitlenene kadar devam ettiğini göstermek için şekildeki düzeneği kurar. İçerisinde fazla miktarda su bulunan tüp yüksek sıcaklığı, az miktarda su bulunan tüp ise düşük sıcaklığı temsil etmektedir. Tüpler arasındaki geçiş serbest bırakıldığında iki tüpteki sıvı seviyesi eşitlenir. Ayşe öğretmen, bu gösterimle ısı alışverişi sonucunda cisimlerin sıcaklıklarının eşitlendiği bilgisini, analoji yoluyla öğrencilerine göstermiştir.



Şekil 1



Şekil 2

Bu gösterimin, öğrencilerde sebep olabileceği bir kavram yanılgısı yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı sıvı gibi bir maddedir
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

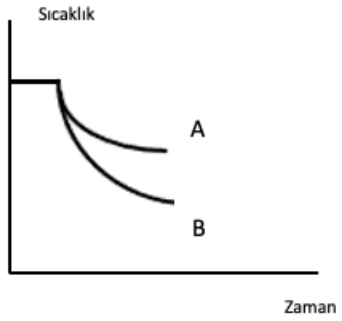
APPENDIX E

COMPREHENSIVE ITEM POOL

Knowledge Of Student Understanding

KSU.1

A physics teacher makes an activity in class. During the activity, students put 100 g of ice in blocks into a container filled with water (container A), and 100 g of ice broken into small pieces (container B) into another container containing the same amount of water. Students observe the temperature change of the water in both containers and create graphs. A student creates the graph in the figure after 50 seconds of observation.



The student interprets the graph as follows: “The water in container B cooled both faster and more than the water in container A. Crushed ice cooled the water more than ice in blocks. The ice pieces gave off more heat because the area in contact with the water was larger."

What could be the reason for the mistake that stands out in the student's comment?

Classification	Criteria
Correct (1)	The following answer is given: • The student did not wait long enough. If he had waited long enough, he would have observed that the final temperature of the water in the two containers was the same, even though the cooling rates were different.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.2

A physics teacher requested his students to do two activities.

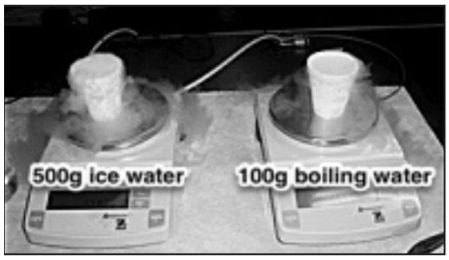
> Activity 1: Students put one hand in a bowl of ice water and the other hand in a bowl of hot water and wait for a while. Students then put both hands into a bowl of room temperature water and share their experiences.
>
> Activity 2: Students first touch a metal and a wooden spoon with their hands and try to estimate their temperatures. After noting their predictions, they measure the temperatures of the metal and wooden spoon with the help of a thermometer and compare them with their previous predictions.

Which misconception of the students might the teacher have primarily wanted to change with these two activities?

Classification	Criteria
Correct (1)	The following answers is given: • Our skin is a good thermometer
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.3

A physics teacher makes an experiment in class. He places containers filled with liquid nitrogen in 500 g of ice water and 100 g of boiled water. The initial temperatures and amounts of liquid nitrogen in the two containers are equal. The teacher asks the students to predict which container's nitrogen will evaporate more. It also says that the boiling point of nitrogen is -198 °C.



Which of the following is a wrong guess that students can make? You can make multiple markings.

500 g of ice water evaporates more nitrogen.	
100 g of boiled water evaporates more nitrogen.	+
500 g of ice water and 100 g of boiled water evaporate equal amounts of nitrogen.	+

What are students' misconceptions that cause them to make wrong guesses?

Classification	Criteria
Correct (1)	One of the following answers is given: • Substances at higher temperatures always give off more heat. • Temperature is the measure of the heat a substance will give off.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.4

A physics teacher prepares the following question to identify students' misconceptions in a lesson on heat conduction.

"Ayşe and Ahmet clean the garden of their house on a cold winter day. While Ayşe uses a broom with a wooden handle, Ahmet uses a broom with a metal handle. While Ayşe is sweeping the garden without any problems, Ahmet feels his hands are cold. What could be the main reason why Ahmet feels this way?"

If you asked your students the same question, what would be the possible wrong answers your students could give to the question? List all the wrong answers that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The temperature of metal is lower than wood. • The specific heat of the metal is higher. • There was a coldness transfer from the metal to Mehmet's hand.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.5

A student interprets a heat-temperature graph as follows:

“When we examine the graph, we see that there is a relationship between the heat given to the substance and the temperature. As the amount of heat given to the mercury increases, the temperature of the mercury also increases. For example, while the temperature of mercury in the 1st second is 42 °C, it becomes 84 °C in the 5th second. In other words, the temperature in the fifth second is exactly twice the temperature in the first second.”

What might be the misconceptions that stand out in the student's comments? List all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • 84 °C is twice as high as 42 °C. • The temperature may be multiples of its magnitude.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.6

A physics teacher asks his students the following discussion question.

Hilal takes out a bottle of juice and a bottle of soda from the refrigerator. She lets the bottles sit on the table for 20 minutes. Knowing that juice and soda bottles receive equal amounts of heat after twenty minutes, what quantities are exactly the same after that time? (A)Internal energy changes (B) Temperatures (C) Internal energies

What could be the misconceptions that might cause your students to give wrong answers?

Classification	Criteria
Correct (1)	The following answer is given: • When the same amount of heat is given to different substances, their final temperatures are the same.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.7

A physics teacher asks his students the following question and asks them to discuss it in groups.

During the winter, icicles form on the roofs of some houses. In the morning, sunlight hits the icicles, and the icicles receive heat. What are the possible and definite changes that will occur on the icicles?

At the end of the group discussions, the teacher notes the answers given by each student group on the board in two categories:

Changes that are likely to occur in the icicles	Changes that are certain to occur in the icicles
-Its density decreases. -It turns from ice to liquid.	Internal energy increases. -The temperature increases. -The heat increases.

What misconceptions do you notice in the answers given by students?

Classification	Criteria
Correct (2)	Two of the following answers are given: • The temperature of every substance that receives heat increases. • Substances possess heat.
Partially correct (1)	• One of the following answers is given: • The temperature of every substance that receives heat increases. • Substances possess heat.
False/ irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.8

In a class on heat conduction, a physics teacher gives a class discussion about why woolen clothes keep people warm. At the end of the discussion, students are asked to give similar examples they encounter in daily life. Some examples given by students are as follows:

Elif: We warm our hands when they are cold outside on the heater.

Barış: Car door handles are made of plastic to prevent damage in extremely cold weather.

Yeşim: We use double-storey windows to prevent heat loss in our home.

Efe: We cover hot foods with aluminum foil to prevent them from cooling quickly.

If you asked the same question in your class, which answer or answers would your students also give?

Elif	+
Barış	+
Yeşim	
Efe	+

What might be the misconceptions that cause your students to give these answers? Write down all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • Woolen clothes gives heat. • Metals are insulators.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.9

Teacher Emre introduces different types of temperature scales in his physics class. Students measure and report the temperature of boiling water with Celsius and Fahrenheit thermometers. After completing the measurement, a student asks the following question: "We used two thermometers to measure the temperature of the same water, why did we get different results?"

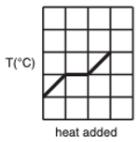
When you evaluate the question asked by the student, write down one of the difficulties you think the student has.

Classification	Criteria
Correct (1)	The following answer is given: • The student had difficulty understanding that the magnitude of the measured temperature depends on the scaling of the thermometer.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

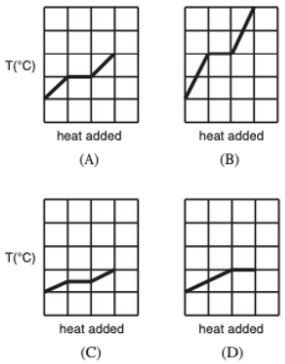
KSU.10

Teacher Ayşe asked the following question in a physics exam.

The heat-temperature graph of a certain amount of water which given heat is as follows:



When the same amount of heat is given to water whose mass is doubled, what will the heat-temperature graph of water look like?



Which of the following is one of the wrong answers that students can give to this question? (You can mark more than one).

A	
B	+
C	
D	

Write down the students' misconceptions that caused them to give wrong answers.

Classification	Criteria
Correct (1)	Options A, B and C are chosen AND One or more of the following answers are given: • The amount of a substance given heat does not affect the rate of temperature change. • The melting temperature of a substance depends on its amount/is not constant. • The student constructed a wrong ratio mathematically.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

KSU.11

In a lesson where condensation is discussed, the teacher asks the students the following question.

“Some ice water is placed in a jar at room temperature. After 15 minutes, it is observed that the surroundings of the jar are wet. What is the reason for the wetness around the jar?”

What are the possible wrong answers that students can give to this question? List all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The water formed by the melting ice passed from the glass to the surface. • The coldness coming from the glass caused the air to turn into water.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.12

Students heat water in two different glasses, foam and aluminum, and measure the temperature change of the water over time. Based on their findings, they explain which glass is more insulating and why. At the end of the experiment, the students were asked: "What material should be used to keep a soda bottle cold?" question is asked. Seventy-five of the students answer aluminum instead of foam.

What are the misconceptions of students who answer the question incorrectly?

Classification	Criteria
Correct (1)	One of the following answers is given: • Metals keep cold. • Metals are insulators.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.13

In a physics lesson, the teacher asks her students the following question:

A student goes to the sea on a very hot summer day. He fills a bucket with sea water and measures its temperature as 16 degrees. The student also directly measures the temperature of sea water as 16 degrees with the same thermometer. As a result of his measurements, the student makes the following inference: "Since both water sources are at the same temperature, the heat energy they have is equal." Do you agree with the student's inference?

Seventy-five percent of the students answer "yes" to this question.

Write the misconception that caused the students to give this answer.

Classification	Criteria
Correct (1)	One of the following answers is given: • Heat is one of the internal properties of matter. • Substances possess heat.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.14

Some concepts are used in daily life far from their scientific meaning. Below are two examples of this:

• A thermos seller advertises by saying that the inner and outer surfaces of the thermoses he sells are made of metal.
• Restaurant owners cover the food with aluminum foil when delivering it to homes.

Write down the misconceptions that these two sample applications may create in students.

Classification	Criteria
Correct (1)	One of the following answers is given: • Metals are insulators. • Metals absorb heat. • Metals keep cold.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.15

In a physics lesson where the subject of thermal equilibrium was discussed, the teacher asked the students the following question.

500 g of hot water at 80 degrees was mixed with 500 g of cold water at 40 degrees. How does the temperature of hot and cold water change (increase/decrease/remain unchanged)? Explain.

A student's answer to the question is as follows:

When hot water and cold water are mixed, the temperature of both hot water and cold water changes because there is a temperature transfer from hot water to cold water. The temperature of the hot water decreases and the temperature of the cold water increases until the temperature of these two waters becomes equal.

What is the misconception(s) that stands out in the student's answer?

Classification	Criteria
Correct (1)	The following answer is given: • There is a temperature transition between substances.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.16

Teacher Emre drew the following table on the blackboard during a class discussion.

	A	B
Mass	2 g	25 g
Specific heat	$4.0\frac{J}{°C \times g}$	$2.0\frac{J}{°C \times g}$
Temperature	30 °C	30 °C

The teacher asked, "What happens if substances A and B come together in a thermally insulated environment?" and requests the students to discuss.

Which of the following is one of the wrong answers that students can give to this question? (You can mark more than one)

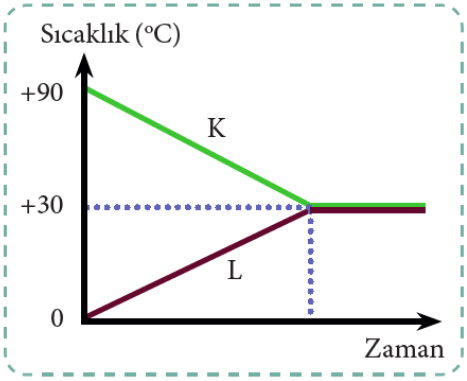
Heat flow is from A to B.	+
Heat flow is from B to A.	+
There is no heat flow.	

Write down the students' misconceptions that caused them to give wrong answers.

Classification	Criteria
Correct (1)	One of the following answers is given: • The mass, specific heat or heat capacity of the substance are among the factors that determine whether heat exchange will occur or not. • Whether heat exchange occurs or not depends on factors other than the temperatures of the substances.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.17

A physics teacher asks her students to interpret the graph in the figure.



One of the students commented as follows: “Initially, the heat of object K is higher than the heat of object L. Since the heat of body K is higher, its internal energy is higher than L. Over time, there was a temperature transition from K to L, the temperature of K decreased and the temperature of L increased."

What are the misconceptions that stand out in the student's comments?

Classification	Criteria
Correct (1)	One of the following answers is given: • Substances possess heat. • Internal energy is a measure of the total heat of a substance. • Temperature is a quantity that can be transmitted.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.18

A teacher asked the following question to measure students' prior knowledge when starting the topic of heat and temperature.

"On a hot summer day, Pelin pours herself a glass of lemonade and adds ice to it. After ten minutes, Pelin notices that the ice has melted and the lemonade has become cold. How do you think the lemonade could have gotten cold?

List possible wrong answers that students might give to this question.

Classification	Criteria
Correct (1)	The following answers are given: • Coldness has passed from ice to lemonade. • The warmth transferred from lemonade to ice. • Warmth has passed from lemonade, and coldness has passed from ice.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.19

In a physics class, one of the students comments:

The internal energy of boiling water in the kettle is greater than the internal energy of ice cubes in the freezer because the temperature of the water is higher.

What is the problematic thought that stands out in the student's comment?

Classification	Criteria
Correct (1)	The following answers are given: • The student did not take into account mass, which is another variable on which internal energy depends. • The student thought that internal energy depends only on temperature.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.20

Students created the following hypotheses in the physics class. Please indicate whether these statements are hypotheses or not.

Statement	Hypothesis	Not hypothesis
The more water is heated, the more its temperature increases.	+	
The temperature change of a substance depends on many factors.		+
The amount of heat given to a substance is related to the change in temperature of that substance.	+	

KSU.21

Teacher Ayşe will use an analogy in a lesson on heat flow. She sets up the mechanism in the figure to show that heat movement is from high temperature to low temperature and continues until the temperatures equalize. The tube with a large amount of water represents high temperature, and the tube with a small amount of water represents low temperature. When the passage between the tubes is released, the liquid level in the two tubes equalizes. With this demonstration, teacher Ayşe showed her students that the temperatures of objects are equalized as a result of heat exchange.



Şekil 1



Şekil 2

Write a misconception that this representation may cause in students.

Classification	Criteria
Correct (1)	The following answer is given: • Heat is a substance like a liquid.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.22

In a class where the subject of thermal balance is discussed, students perform activities in groups. Heated steel screws are placed into a container filled with water and temperature changes are observed. After the event, the following conversation takes place between the teacher and the students:

Teacher: Can one of you tell us what you observed?
Elif: We heated a screw and threw it into water... The temperature of the water increased by a certain amount. When we added more screws, the temperature of the water increased even more.
Teacher: OK… So what is the purpose of the activity? What did you learn?
Ali: I think we learned the effect of the mass of hot objects... Because their total calories are more... For example, let's say one screw has 5 calories... Thus, five screws have 25 calories.
Ege: Yes, that's why the water got hotter as the number of screws increased.

State the misconception that stands out in the above dialogue.

Classification	Criteria
Correct (1)	One of the following answers is given: • Heat is one of the internal properties of matter. • Substances possess heat.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

Knowledge Of Instructional Strategies

IS.1

A physics teacher candidate who is doing an internship at your school will prepare a lesson plan for the topic 'specific heat'. The teacher candidate wants to base the lesson on a student's thought. After doing some research, he decides to focus on the student conception that "all metals have the same specific heat." The prospective teacher asks you for ideas about experiments that can be designed within the scope of this idea.

Design a simple experiment that you can recommend to the teacher candidate.

Classification	Criteria
Correct (1)	The following answer is given: • A simple experiment is designed to examine the change in temperature of two different metals depending on the heat given or received.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

What could be the reasons why the teacher candidate bases the lesson on misconceptions? List all the ideas that come to your mind.

Classification	Criteria
Correct (1)	Two of the following answers are given: • It enables students to connect their existing thoughts with new topics. • Students are surprised to discover that their thoughts are not correct and become ready to learn new information. • Students' misconceptions should be replaced with scientifically correct thoughts. • Student understandings are very difficult to change, but can be changed using good teaching methods (Kirschner et al., 2016).
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.2

A physics teacher candidate wants to have students do an activity in his internship course. Creates an interesting activity theme on the topic of heat conduction and prepares the following informative text.

Save the penguins! Penguins living in the poles face the threat of global warming. Don't you want to build houses that will protect penguins from the heat? Let's design a house for penguins!

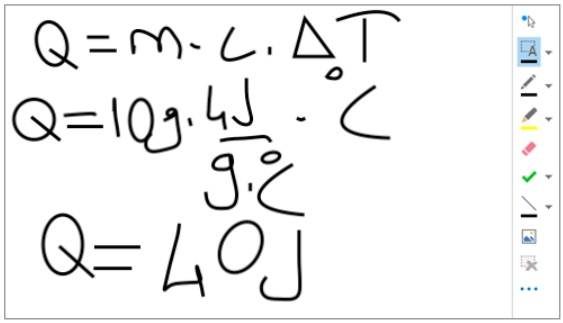
The teacher candidate determines the materials to be used within the scope of the activity: Ice pieces, wool fabric, thermometer.

How can this activity prepared by the teacher candidate be organized in a way that is more suitable for scientific research steps? Write down any suggestions that come to your mind.

Classification	Criteria
Correct (1)	Tthe following answer is given: • A control mechanism should be added to the experiment: A control variable or variables should be used to test which house type is more livable for penguins.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.3

The problem solved by a physics teacher is as shown in the figure.



What might be the importance of using units when calculating for a physics teacher? List all the ideas that come to your mind.

Classification	Criteria
Correct (1)	Two of the following answers are given: • Numbers do not represent a physical magnitude on their own, they gain meaning with units. • Units make results understandable and meaningful. • Using units makes it easier to spot errors. • Constant use of units raises awareness of whether conversion is necessary before calculating. • Being accustomed to using units makes it easier to learn formulas and make connections (Kirschner et al., 2016).
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.4

A physics teacher used the following analogy in his heat-temperature lesson: “To pop corn, corn kernels are added to a pot and placed on the stove. As time passes, the corn grains begin to move in the pot.”

Which of the following magnitudes can be explained by using this analogy?

Specific heat	
Temperature	+
Heat capacity	
Convection	
Conduction	

What could be the limitations of the analogy?

Classification	Criteria
Correct (1)	The following answer is given: • The structure of substances that receive heat and whose temperature increases does not change; in the analogy, the structure of corn that receives heat changes.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.5

A physics teacher asked his students, "What will be the equilibrium temperature if 250 g of water at 90 °C is mixed with 500 g of water at 10 °C?". The teacher identifies two alternative methods for investigating the problem. In the first of these methods, real laboratory materials are used (Figure 1). In the second method, a virtual laboratory (simulation) is used (Figure 2).



Figure 1

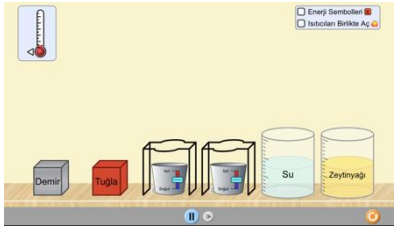


Figure 2

When you think about it in the context of the question asked by the teacher, what advantages might the second method have over the first method?

Classification	Criteria
Correct (1)	One of the following answers is given: • Reducing the time required for thermal equilibrium to occur. • Ease of changing parameters • Ability to work with very high and very low temperatures • Being able to repeat the experiment for liquids at different temperatures • To avoid the influence of confounding variables such as lack of thermal insulation • Safer and less risky as it does not work with high temperatures
False/Irrelevant (0)	An incorrect or irrelevant answer is given OR general answers are given without relating it to the experiment: • More trustworthy • Easier • Low risk • Provides more accurate results
Blank (0)	The question was left unanswered.

IS.6

In a physics class, a prospective teacher starts the lesson with an example of zinc and platinum pieces that have been stored long enough in the refrigerator. He asks students to observe and comment on the pieces. Mert makes the following comment:

The zinc pieces felt cooler than the platinum pieces. The reason for this is that the specific heat of zinc (0.5 kj/kg.C) is higher than the specific heat of platinum (0.13 kj/kg.C). In other words, the amount of heat required to increase the temperature of 1 gram of zinc is more than that of platinum.

a. How should the prospective physics teacher evaluate Mert's statement?

1. Mert made a correct statement ( )
2. Mert made an incomplete/incorrect statement ( )

b. The physics teacher candidate plans to have the following application done as the next step.

Students heat pieces of zinc and platinum. They draw a graph showing the temperature change depending on the heat given.

If you were the teacher candidate, would you use the activity above as the next step?

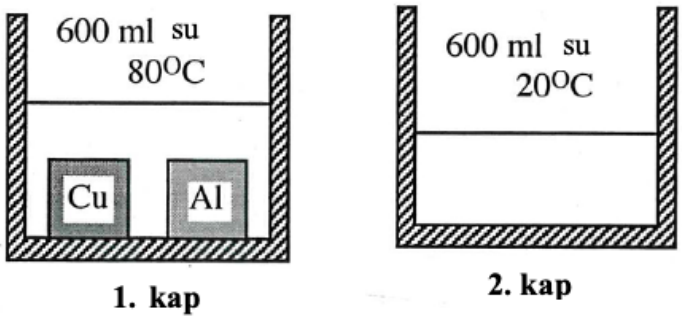
1. Yes ( )
2. No ( )

If yes, how can this activity help strengthen students' understanding?
If your answer is no, how can this activity be organized or what different activities can be used?

Kodlama Şeması	
Classification	Criteria
Correct (1)	• 2 is marked in section “a” and 2 is marked in section “b” and an explanation is made as follows: • Children should do experiments on thermal conductivity, not specific heat. For this purpose, experiments can be carried out using a substance with a high specific heat but low thermal conductivity, or a substance with a low specific heat but high thermal conductivity. Thus, students see that thermal conductivity is not related to specific heat.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.7

A physics teacher candidate gives the following example to his students.



Blocks of copper and aluminum are in thermal equilibrium in a container filled with water. The heat capacity of copper is 200 cal/C and the heat capacity of aluminum is 100 cal/C. The blocks in the first container are transferred to the second container and thermal equilibrium is waited for. How do temperature changes occur in the blocks?

Melike, one of the students, makes the following comment:

The temperature change in the copper block is higher than in aluminum because the heat capacity of copper is greater than aluminum.

a. How should the prospective physics teacher evaluate Melike's statement?

1. Melike made a correct statement ( )
2. Melike made an incomplete/incorrect statement ( )

b. The physics teacher candidate plans to have the following application done as the next step.

Students examine the temperature change in copper and aluminum blocks with the help of a thermometer. They draw a graph of temperature change over time.

If you were the teacher candidate, would you use the activity above as the next step?

1. Yes ( )
2. No ( )

If yes, how can this activity help strengthen students' understanding?

If your answer is no, how can this activity be organized or what different activities can be used?

Classification	Criteria
Correct (1)	• 2 is marked in part a and 1 is marked in part b and an explanation is made as follows: • At the end of thermal equilibrium, all substances are at the same temperature. There is no relationship between the temperature change and the heat capacity of objects that have reached thermal equilibrium. The application chosen by the teacher is important because it shows that there is an equal temperature change in both blocks after a certain period of time.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.8

In a physics class where heat and temperature-related quantities were discussed, one of the students made the following comment:

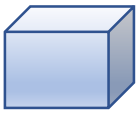
When we go to the park on cold winter days, we want to sit on wooden benches instead of metal benches. Metal benches are colder than wooden benches, so they make us cold.

If you were the physics teacher, what method would you follow to correct the student's misconceptions?

Classification	Criteria
Correct (1)	One of the following answers is given: • The teacher addresses the student's misconceptions and adopts a conceptual approach. He/she has various scientific practices performed in order to form scientifically correct thought. • The student's misconception is stated.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.9

A student thinks that the cooling rate of substances depends on volume and surface area and designs an experiment. In the experiment, he examines the cooling rates of the two different water tanks.

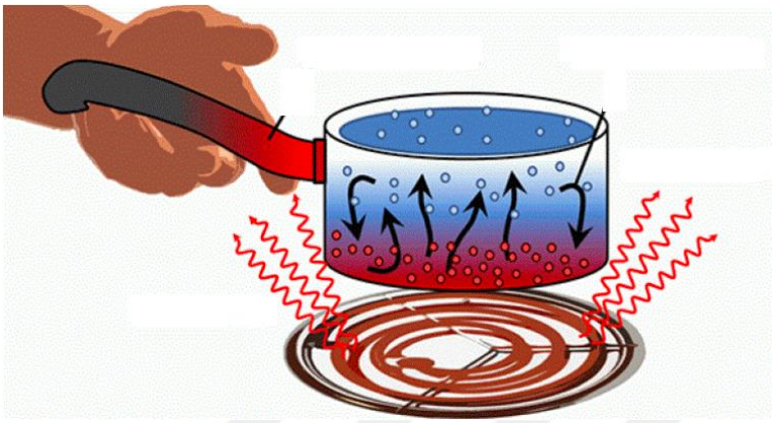
 Surface area = $6m^2$ Volume = $2m^3$	 Surface area = $5m^2$ Volume = $3m^3$

Write the feature of scientific application that the student neglected in the experiment he designed.

Classification	Criteria
Correct (1)	One of the following answers is given: • Two variables are examined simultaneously (volume and surface area); Only a single factor can be changed during an experiment and other variables must be kept constant. • The cooling rate in warehouses with different surface areas should be compared under equal conditions (in tanks with the same volume). • The cooling rate in tanks with different volumes should be compared under equal conditions (in tanks with the same surface area).
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.10

Teacher Emre used the following illustration in a lesson where he taught the heat and temperature unit.



List the concepts/information that teacher Emre aims for the students to learn by using this representation.

Classification	Criteria
Correct (2)	Three of the following answers are given: • Energy transmission ways (Conduction, convection, radiation)
Partially correct (1)	Two of the following answers are given: • Energy transmission ways (Conduction, convection, radiation)
False/ irrelevant (0)	One of the following answers are given: • Energy transmission pathways (Conduction, convection, radiation) OR An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.11

In a class where you cover heat conduction in solids, you want to emphasize the steps of scientific research. You have prepared an outline of the steps and experimental stages to be followed in the lesson.

Complete the missing in-course steps and experimental stages in the table below.

In-Class Steps	Experimental Phase
On a cold winter day, a bench made of aluminum feels colder than a bench made of brass.	Observation
Which material conducts heat better?	(A)
(B)	Hypothesis formation
Equal amounts of heat are given to water in two different glasses made of aluminum and brass.	(C)
The temperature change of the water in two glasses is reported and a graph is created.	(D)
The temperature change of water in an aluminum cup is greater than the temperature change of water in a brass cup.	(E)
(F)	Result

	Criteria		
Classification	(A)	(B)	(C)
Correct (1)	One of the following answers are given: • Formulating problem • Asking a research question	One of the following answers are given: • Aluminum conducts heat better than brass. • Aluminum is a better conductor.	One of the following answers are given: • Planning the experiment
False/ irrelavant (0)	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.	The question was left unanswered.	The question was left unanswered.

	Criteria		
Classification	(D)	(E)	(F)
Correct (1)	One of the following answers are given: • Collecting data • Making measurements	One of the following answers are given: • Analysis of data • Evaluation • Result	One of the following answers are given: • Aluminum conducts heat better than brass. • Aluminum is a better conductor.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.	The question was left unanswered.	The question was left unanswered.

	Number of correct statements	Classification
Score	6	2
	5	
	4	1
	3	
	2	0
	1	
	0	

IS.12

The following activity suggestion is included in a book consisting of experiments that can be done in physics class:

A balloon is attached to the end of an empty glass bottle and the bottle is placed in a large container. Hot water is poured into the container and the balloon is seen to inflate over time.

This activity is called an experiment in the book, but it does not reflect the characteristics of a real scientific experiment. What could be the reason for this? Write down all the thoughts that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The effect of one variable on another variable is not measured and reported. • The experiment is not repeated with water at different temperatures.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.13

The following activity suggestion is included in a book consisting of experiments that can be done in physics class:

A jar is filled with water and placed in a sunny area of the classroom. Students note how the water level changes from day to day.

Indicate which scientific research step, rather than experiment, is used in this activity.

Classification	Criteria
Correct (1)	The following answer is given: • Observation
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.14

A physics teacher used the following analogy in his heat and temperature lesson: “Workers stack sandbags on top of each other and build a wall. Some workers are tougher than others. In other words, it can carry sandbags and create walls for a long time without getting too tired. Some workers can work very fast. But just because they work fast doesn't mean they can work for long periods of time.”

In the analogy he used, the physics teacher likened the wall made of sandbags to "transferred heat". Which of the following could be the other quantities simulated in this example?

Specific heat-Internal energy	
Heat capacity-Internal energy	
Internal energy-conductivity	
Heat capacity- conductivity	+

Classification	Criteria
Correct (1)	Only the “Heat capacity-Conductivity” option is selected.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

IS.15

A physics teacher makes the demonstration in the figure in class. He adds ice colored with blue food coloring and hot water colored with red food coloring into a plastic container filled with water and asks the students to observe the water.



Figure

Which of the following activities might the teacher have used this demonstration to explain?/ Which of the following events might the teacher have wanted to explain using this demonstration? You can make more than one mark.

Movement of magma fluid	+
Thawing frozen meat	+
Burning of candle	
Working of hot air balloons	+
Operation of the microwave oven	
Formation of breeze winds	+
Heating a room with a stove	+

Classification	Criteria
Correct (1)	Three, four or five correct choices were made.
False/Irrelevant (0)	Two, one or zero correct choices were made.
Blank (0)	The question was left unanswered.

IS.16

In a physics class, you introduced the terms heat, specific heat and heat capacity to students. You want to highlight the connections and differences between these three concepts.

How would you explain to students the difference between 100 calories, 100 Cal/ g^{o}C, and 100 cal/°C? Give examples that highlight the connections between these three dimensions and that may be meaningful to students.

Classification	Criteria
Correct (1)	Two of the answers are given below. • To increase the temperature of an object, 100 calories of heat is given to that object. These 100 calories increase the temperature of a 1 gram object with a specific heat of 100 Cal/ g^{o}C by 1 degree. The amount of heat that must be given to increase the temperature of an object with a heat capacity of 100 cal/°C by one degree is 100 calories. • The connection between heat and specific heat: The amount of heat that must be given to increase the temperature of a one gram object with a specific heat of 100 Cal/ g^{o}C by 1 degree is 100 calories. • The connection between heat and heat capacity: It is the amount of heat that an object must give in order for its temperature to decrease by one degree. • The relationship between specific heat and heat capacity: While the amount of heat that must be given to increase the temperature of an object by 1 degree refers to the heat capacity, the amount of heat that must be given to increase the temperature of 1 gram of the same object by one degree refers to the specific heat.
False/ irrelavant (0)	• Yanlış ya da ilişkisiz bir cevap verilir.
Blank (0)	Soru cevapsız bırakıldı.

IS.17

A physics teacher candidate will have students do an experiment within the scope of the heat and temperature unit. The materials used in the experiment and the conduct of the experiment are as follows:

Materials: 2 pieces of black fabric, 2 beakers, stretch film, thermometer, light source

How to do the experiment:

1. Fabric pieces are placed in beakers and the mouth of one beaker is covered with stretch film.
2. The initial temperatures of the fabric pieces in two beakers are measured.
3. Heat is given to the beakers using a light source.
4. After a while, the temperatures of the fabric pieces inside the beakers are measured and compared.

What could be the purpose of this experiment designed by the prospective physics teacher? Explain.

Classification	Criteria
Correct (1)	One of the following answers is given: • Showing that one of the causes of global warming is the Greenhouse effect. • Showing that the Greenhouse effect increases the Earth's temperature
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.18

Cognitive disequlibrium is the incompatibility that exists between people's thoughts and the situations they encounter in real life.

Example:

In a physics class, students add ice to 0 degree water and note the temperature change of the water over time. The teacher notices that students experience cognitive dissonance after the activity.

Which of the following is an activity that a teacher who wants to use the cognitive equilibrium? You can make more than one mark.

Covering a piece of ice with wool and measuring the temperature change	+
Measuring the temperature change of water by placing a hot metal spoon into it	
Measuring the temperatures of metal and wooden benches in the park on a cold winter day	+
Comparing the temperatures at which frozen olive oil and ice begin to melt	

Classification	Criteria
Correct (2)	Not choosing 2. and 4. options AND Chopsing 1. and 3. options
Partially correct (1)	Not choosing 2. and 4. options AND Chopsing 1. or 3. options
False/Irrelevant (0)	Choosing one or two of the 2. and 4. options
BLANK (0)	The question was left unanswered.

IS.19

A physics teacher made the following activity in his class.

Hot water, cold water and room temperature water are placed in three different jars. When a drop of food coloring is added to the jars, it is seen that the dye in hot water spreads faster than the dye in cold water.

What inference/conclusion might the teacher want the students to reach with this activity?

Classification	Criteria
Correct (1)	One of the following answers is given: • The speed of the particles of substances that receive heat increases. • When substances are hot, the speed of their particles is faster.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.20

A physics teacher identifies two different activities that can be alternatives to each other and decides to use them in the lesson.

Activity 1: A balloon is touched to a candle and it starts to burn. Water is filled into the same balloon and touched to the candle again. It is observed that the balloon does not burn.

Activity 2: A paper money is touched to the candle and it starts to burn. The same paper money does not burn when wrapped around a copper rod and touched by a candle.

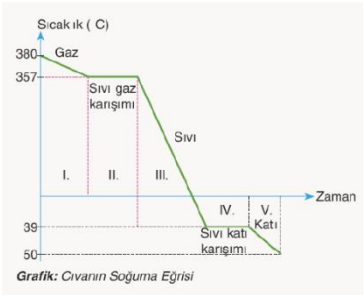
What concepts/information might the teacher aim for the students doing the activities to learn? List it.

Classification	Criteria
Correct (1)	One of the following answers is given: • Heat conduction
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

Knowledge Of Curriculum (KC)

KC.1

Which of the following contents might a student who has just started 9th grade have never seen before?



Grafik: Civanın Soğuma Eğrisi

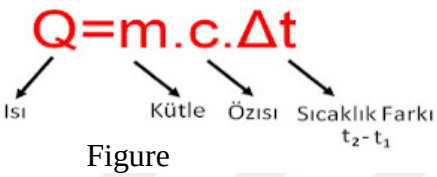
Figure 1

Tablo: Bazı Maddelerin Öz Isıları

Madde	Öz Isı (J/g°C)
Bakır	0,37
Alüminyum	0,90
Çinko	0,39
Kurşun	0,13
Nikel	0,45
Demir	0,46

Kaynak: Beichner, Serway, Fen ve Mühendislik İçin Fizik 1

Figure



Figure

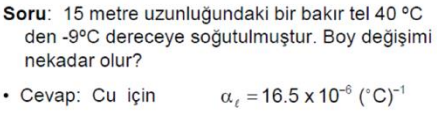


Figure 4

Figure 1	
Figure 2	
Figure 3	+
Figure 4	+

KC.2

Which of the following contents might a student who has completed the 9th grade have seen before?

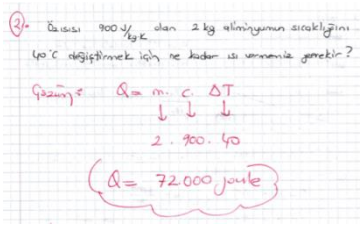
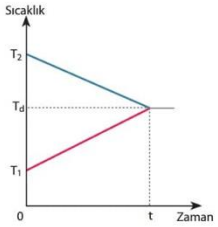


Figure 1

Kütlesi m, öz ısısı c olan bir cisme Q kadar ısı verildiğinde sıcaklığındaki değişim T oluyor. **Buna göre aynı cins malzemeden yapılmış 2m kütleli bir başka cisme 4Q kadar ısı enerjisi verilirse sıcaklığındaki değişim kaç T olur?**

Figure 2



$$|Q_{alınan}| = |Q_{verilen}|$$

$$m_1.c_1(T_d - T_1) = m_2.c_2.(T_2 - T_d)$$

$$T_d = \frac{m_1c_1T_1 + m_2c_2T_2}{m_1c_1 + m_2c_2}$$

$$T_d = \frac{C_1T_1 + C_2T_2}{C_1 + C_2} \text{ olur.}$$

Figure 3

Figure 1	
Figure 2	+
Figure 3	

KC.3

Which of the following contents might all students who have taken physics courses in high school in the last 15 years have seen? You can make more than one mark.

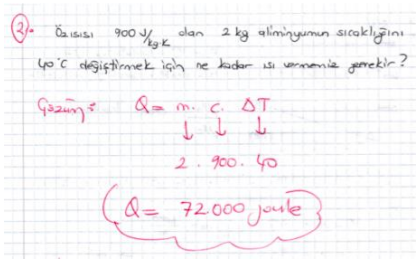


Figure 1

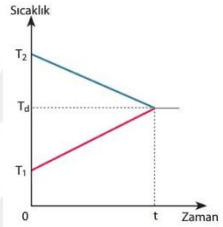
Kütlesi m, öz ısısı c olan bir cisme Q kadar ısı verildiğinde sıcaklığındaki değişim T oluyor. **Buna göre aynı cins malzemeden yapılmış 2m kütleli bir başka cisme 4Q kadar ısı enerjisi verilirse sıcaklığındaki değişim kaç T olur?**

Figure 2

Soru: 15 metre uzunluğundaki bir bakır tel 40 °C den -9°C dereceye soğutulmuştur. Boy değişimi nekadar olur?

- Cevap: Cu için $\alpha_\ell = 16.5 \times 10^{-6}\ (^\circ C)^{-1}$

Figure 3



$$|Q_{alınan}| = |Q_{verilen}|$$
$$m_1.c_1(T_d - T_1) = m_2.c_2.(T_2 - T_d)$$
$$T_d = \frac{m_1c_1T_1 + m_2c_2T_2}{m_1c_1 + m_2c_2}$$
$$T_d = \frac{C_1T_1 + C_2T_2}{C_1 + C_2} \text{ olur.}$$

Figure 4

Figure 1	
Figure 2	+
Figure 3	
Figure 4	

KC.4

Activity 1: Students compare the heat conduction rates of different types of solids.
Activity 2: Students model the cycle of air heated by the heater in the room.
Activity 3: Students develop a project to increase the insulation of a house with heating problems.
Activity 4: Students make budget calculations for alternative solution suggestions that will increase insulation.
Activity 5: Students compare the heating costs of a house with thermal insulation and a house without it.
Activity 6: Students compare the thermal insulation of different colored buildings.

Considering the principles stated in the curriculum, what are the primary activities that can be done in courses where heat conduction rate is covered?

Activity 1	+
Activity 2	+
Activity 3	+
Activity 4	+
Activity 5	+
Activity 6	

KC.5

A physics teacher uses a Gravzant ring in the lesson.

Fizik öğretmeni bu materyali hangi konuyu/ alt konuyu anlatmak için kullanmış olabilir?

Classification	Criteria
Correct (1)	One of the following answers is given: • Expansion • Expansion of solids
False/ irrelavant (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Blank (0)	Soru cevapsız bırakıldı.

If you were in the teacher's place, what would be the outcome of the lesson using this material?

Classification	Criteria
Correct (1)	The following answer is given: • Students observe that solid materials that receive heat expand.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KC.6

Which of the following are the preliminary information/concepts/quantities that students need to know in order to understand the concept of internal energy? (You can mark more than one).

Power	
Conductivity	
Kinetic energy	+
Potential energy	+
Gravitational force	+

Classification	Criteria
Correct (1)	All options C, D and E are selected.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KC.7

Considering the changes made in the physics curriculum in the 2017-2018 period, which sub-topics of the heat temperature unit have been simplified less than others?

a. Thermal equilibrium
b. Expansion
c. Change of state
d. Energy transfer ways (X)

KC.8

Some changes were made in the physics curriculum in the 2007-2008, 2013-2014 and 2017-2018 periods. In which area can it be said that there has been the least change?

a. Mathematical calculations
b. Measurement and evaluation approach (X)
c. Emphasis on Turkish Islamic scientists
d. Emphasis on values such as justice, self-control, and responsibility

KC.9

Which of the following activities cannot be said to be emphasized for the first time in the 2018 curriculum?

a. Asking students to design cartoons explaining heat conduction pathways
b. Planning a lesson with the art teacher that introduces a special painting technique using heat transfer
c. Making inferences about socioscientific events regarding the use of different energy sources and global warming
d. Discussing the findings of scientists who claim that global warming is not at dangerous levels (X)

KC.10

In which year can it be said that the curriculum published is more detailed on topics such as activity suggestions and teaching strategies used in the course?

a. 1997
b. 2007(X)
c. 2013
d. 2017

KC.11

The order of the units in two different 9th grade lecture books is as follows:

Book 1: Introduction to physical science, matter and its properties, heat and temperature, force and motion, energy, electrostatics

Book 2: Introduction to physical science, matter and its properties, force and motion, energy, heat and temperature, electrostatics

Which book order do you think is more appropriate?

Book 1	
Book 2	+

What might be the advantages of the order in the book you have chosen compared to the other book? Write down all the ideas that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • In terms of heat and temperature, quantities such as speed and energy possessed by matter particles are mentioned. In order to understand the subject of heat and temperature, students need to know the concepts of speed and energy. • The concept of internal energy is related to particle and potential energies.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

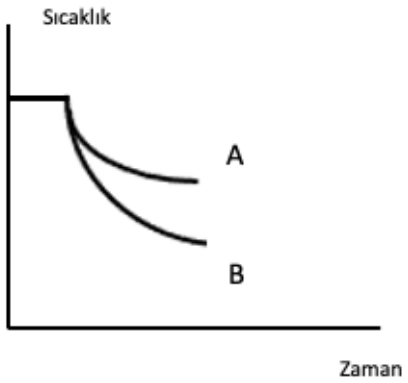
APPENDIX F

TURKISH VERSION OF THE COMPREHENSIVE ITEM POOL

Öğrenci Anlayışları Bilgisi

KSU.1

Bir fizik öğretmeni derste bir etkinlik yaptırır. Öğrenciler aktivite sırasında su dolu bir kaba blok halinde 100 g buz (A kabı), aynı miktarda su bulunan diğer kaba da küçük parçalara ayrılmış 100 g buz (B kabı) koyar. Öğrenciler her iki kaptaki suyun sıcaklık değişimini gözlemleyip grafik oluştururlar. Bir öğrenci 50 saniyelik gözlem sonunda şekildeki grafiği oluşturur.



Öğrenci grafiği şöyle yorumlar: "B kabındaki su A kabındaki suya göre hem daha hızlı hem de daha çok soğudu. Parçalanmış buz, blok halindeki buza göre suyu daha çok soğuttu. Buz parçaları, suyla temas ettiği alan daha büyük olduğu için daha çok ısı verdi."

Öğrencinin yorumunda dikkat çeken yanılgıya sebep olan durum ne olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Öğrenci yeterince beklememiştir. Eğer yeterince bekleseydi, soğuma hızları farklı da olsa, iki kaptaki suyun son sıcaklığının aynı olduğunu gözlemlemiş olurdu.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.2

Bir fizik öğretmeni öğrencilere iki aktivite yaptırır.

1. Aktivite: Öğrenciler bir elini buzlu su dolu bir kaba, diğer elini de sıcak su dolu bir kaba koyup bir süre bekler. Öğrenciler sonrasında iki elini de oda sıcaklığındaki su dolu bir kaba sokar ve deneyimlerini paylaşır.

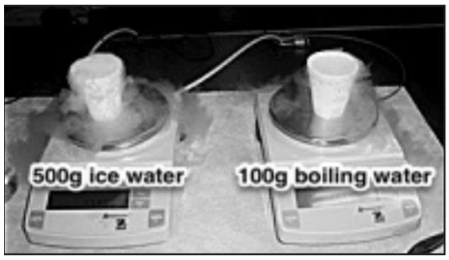
2. Aktivite: Öğrenciler önce birer metal ve tahta kaşığa elleriyle dokunur ve sıcaklıklarını tahmin etmeye çalışır. Tahminlerini not ettikten sonra termometre yardımıyla metal ve tahta kaşığın sıcaklıklarını ölçer ve daha önceki tahminleriyle karşılaştırır.

Öğretmen bu iki aktiviteyle öncelikli olarak öğrencilerin hangi yanılgılı düşüncesini değiştirmek istemiş olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Derimiz iyi bir termometredir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.3

Bir fizik öğretmeni derste bir deney yaptıracaktır. 500 g buzlu su ve 100 g kaynamış su içerisine sıvı nitrojenle dolu kaplar yerleştirir. İki kaptaki sıvı nitrojenlerin ilk sıcaklıkları ve miktarları eşittir. Öğretmen öğrencilerden hangi kaptaki nitrojenin daha çok buharlaşacağını tahmin etmelerini ister. Ayrıca nitrojenin kaynama noktasının -198 °C olduğunu söyler.



Aşağıdakilerden hangisi öğrencilerin yapabileceği yanlış tahminlerdendir? Birden çok işaretleme yapabilirsiniz.

500 g buzlu su daha çok nitrojen buharlaştırır.	
100 g kaynamış su daha çok nitrojen buharlaştırır.	+
500 g buzlu su ve 100 g kaynamış su eşit miktarda nitrojen buharlaştırır.	+

Öğrencilerin yanlış tahminde bulunmasına sebep olan yanılgılı düşünceleri nedir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Yüksek sıcaklıklardaki maddeler her zaman daha çok ısı verir. • Sıcaklık bir maddenin vereceği ısının ölçüsüdür.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.4

Bir fizik öğretmeni, ısı iletimini işleyeceği bir derste öğrencilerin yanılgılı düşüncelerini tespit etmek için aşağıdaki soruyu hazırlar.

"Ayşe ve Ahmet soğuk bir kış gününde evlerinin bahçesini temizler. Ayşe tahta saplı bir süpürge kullanırken, Ahmet metal saplı bir süpürge kullanır. Ayşe bahçeyi sorunsuz bir şekilde süpürürken, Ahmet ellerinin üşüdüğünü hisseder. Ahmet'in böyle hissetmesinin temel nedeni ne olabilir?"

Aynı soruyu öğrencilerinize siz sorsaydınız, öğrencilerinizin soruya verebileceği muhtemel yanlış cevaplar neler olurdu? Aklınıza gelen tüm yanlış cevapları sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Metalin sıcaklığı tahtadan daha düşüktür. • Metalin öz ısısı daha yüksektir. • Metalden Mehmet'in eline soğukluk geçişi olmuştur.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.5

Bir öğrenci bir ısı-sıcaklık grafiğini şöyle yorumlar:

“Grafiği incelediğimizde maddeye verilen ısı ile sıcaklık arasında bir ilişki olduğunu görüyoruz. Cıvaya verilen ısı miktarı arttıkça cıvanın sıcaklığı da artıyor. Örneğin 1. saniyedeki cıva sıcaklığı 42 °C iken 5. saniyede 84 °C oluyor. Yani beşinci saniyedeki sıcaklık birinci saniyedeki sıcaklığın tam iki katı oluyor.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • 84 °C, 42 °C nin iki katıdır. • Sıcaklık büyüklerinin katları olabilir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.6

Bir fizik öğretmeni öğrencilerine aşağıdaki tartışma sorusunu sorar.

Hilal, buzdolabından bir şişe meyve suyu ve bir şişe soda çıkarır. Şişeleri masanın üzerinde 20 dakika boyunca bekletir. Meyve suyu ve soda şişelerinin yirmi dakika sonunda eşit miktarda ısı aldığı bilindiğine göre, bu süre sonunda hangi nicelikleri kesinlikle aynıdır? (A) İç enerji değişimleri (B) Sıcaklıkları (C) İç enerjileri

Aynı soruyu öğrencilerinize siz sorsaydınız, öğrencilerinizin soruya verebileceği muhtemel yanlış cevap şıkları neler olurdu?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • B, C ya da B&C şıkkı söylenir. • A şıkkı söylenmez.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğrencilerinizin yanlış cevap vermesine neden olabilecek yanılgıları düşünceler neler olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Farklı maddelere aynı miktar ısı verildiğinde son sıcaklıkları aynı olur.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.7

Bir fizik öğretmeni öğrencilerine aşağıdaki soruyu sorar ve gruplar halinde tartışmalarını ister.

Kış mevsiminde bazı evlerin çatılarında buz sarkıtları oluşur. Sabahları güneş ışıkları buz sarkıtlarına vurmakta ve buz sarkıtları ısı almaktadır. Göl yüzeyinde gerçekleşmesi muhtemel ve kesin değişiklikler neler olabilir?

Öğretmen grup tartışmaları sonunda her öğrenci grubunun verdiği cevapları iki kategori şeklinde tahtaya not eder:

Gölde gerçekleşmesi muhtemel değişiklikler	Gölde gerçekleşmesi kesin değişiklikler
-Yoğunluğu azalır. -Buz halden sıvı hale dönüşür.	-İç enerjisi artar. -Sıcaklığı artar. -Isısı artar.

Öğrencilerin verdiği cevaplarda dikkatinizi çeken yanılgılı düşünceler nelerdir?

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevaplardan ikisi verilir: • Isı alan her maddenin sıcaklığı artar • Maddelerin ısısı vardır
Kısmen doğru (1)	Aşağıdaki cevaplardan biri verilir: • Isı alan her maddenin sıcaklığı artar • Maddelerin ısısı vardır
Yanlış/ilgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.8

Bir fizik öğretmeni, ısı iletimini işlediği bir derste yünlü giysilerin insanları neden sıcak tuttuğuyla ilgili bir sınıf tartışması yapar. Tartışma sonunda öğrencilerden günlük hayatta karşılaştıkları benzer örnekler vermelerini ister. Öğrencilerin verdiği bazı örnekler şu şekildedir:

Elif: Dışarıda üşüyen ellerimizi kaloriferde ısıtırız.

Barış: Arabaların kapı kolları aşırı soğuk havalarda zarar görmememiz için plastikten yapılır.

Yeşim: Evimizdeki ısı kaybını önlemek için çift katlı pencereler kullanırız.

Efe: Çabuk soğumaması için sıcak yiyecekleri alüminyum folyoyla kaplarız.

Aynı soruyu sınıfınızda sorsaydınız, öğrencilerinizin verebileceği yanlış cevaplar hangi öğrenci ya da öğrenciler gibi olurdu?

Elif	+
Barış	+
Yeşim	
Efe	+

Öğrencilerinizin bu cevapları vermesine neden olan yanılgılı düşünceler neler olabilir? Aklınıza gelen bütün yanılgılı düşünceleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Yünlü giysiler insanı ısıtır. • Metaller yalıtkandır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.9

Emre öğretmen, fizik dersinde farklı tür sıcaklık ölçeklerini tanıtmaktadır. Öğrenciler kaynayan suyun sıcaklığını Selsiyus ve Fahrenhayt termometreleriyle ölçüp raporlar. Bir öğrenci ölçümü tamamladıktan sonra şu soruyu sorar: "Biz iki termometreyi de aynı suyun sıcaklığını ölçmek için kullandık, neden farklı sonuçlar elde ettik?".

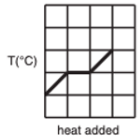
Öğrencinin sorduğu soruyu değerlendirdiğinizde, öğrencinin sahip olduğunu düşündüğünüz zorluklardan birisini yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Öğrenci, ölçülen sıcaklığın büyüklüğünün, termometrenin ölçeklendirmesine bağlı olduğunu kavramakta zorlanmıştır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

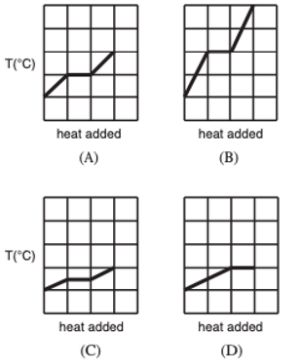
KSU.10

Ayşe öğretmen bir fizik sınavında aşağıdaki soruyu sormuştur.

Isı verilen belirli bir miktarda suyun ısı-sıcaklık grafiği aşağıdaki gibidir.



Aynı miktarda ısı, kütlesi iki katına çıkarılan suya verildiğinde suyun ısı sıcaklık grafiği nasıl olur?



Aşağıdakilerden hangisi öğrencilerin bu soruya verebileceği yanlış cevaplardan biridir? (Birden fazla işaretleme yapabilirsiniz).

A	
B	+
C	
D	

Öğrencilerin yanlış cevap vermelerine neden olan yanılgılı düşüncelerini yazınız.

Kodlama	Kriter
Doğru (1)	A, B ve C şıkları söylenir VE Aşağıdaki cevaplardan ikisi verilir: • Isı verilen bir maddenin miktarı, sıcaklık değişim hızını etkilemez. • Bir maddenin erime sıcaklığı, miktarına bağlıdır/sabit değildir. • Öğrenci matematiksel olarak yanlış oran kurmuştur.
Yanlış/İlgisiz (0)	• Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	• Soru cevapsız bırakıldı.

KSU.11

Yoğunlaşma olayının işlendiği bir derste, öğretmen öğrencilere aşağıdaki soruyu sorar.

“Oda sıcaklığındaki bir kavanoz içerisine bir miktar buzlu su konur. 15 dakika sonra kavanozun etrafının ıslak olduğu gözlemlenir. Kavanozun etrafında ıslaklık oluşmasının sebebi nedir?”

Öğrencilerin bu soruya verebilecekleri muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Eriyen buzun oluşturduğu su camdan yüzeye geçmiştir. • Camdan gelen soğukluk havanın suya dönüşmesine neden olmuştur.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.12

Öğrenciler köpük ve alüminyum olmak üzere iki farklı bardaktaki suyu ısıtır ve suyun sıcaklık değişimini zamana göre ölçerler. Bulguları doğrultusunda hangi bardağın neden daha yalıtkan olduğunu açıklarlar. Deney sonunda öğrencilere "Bir sodayı soğuk tutmak için hangi malzemeden yapılmış bir kap kullanılmalıdır?" sorusu sorulur. Öğrencilerin %75'i köpük yerine alüminyum cevabını verir.

Soruya yanlış cevap veren öğrencilerin yanılgılı düşünceleri nedir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Metaller soğuk tutar. • Metaller yalıtkandır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.13

Bir öğretmen fizik dersinde öğrencilerine aşağıdaki soruyu sorar:

Bir öğrenci sıcak bir yaz gününde havuza girer. Bir kovaya havuz suyu doldurur ve sıcaklığını 25 derece olarak ölçer. Öğrenci, aynı termometreyle havuz suyunun sıcaklığını da 25 derece olarak ölçer. Öğrenci, ölçümleri sonucunda şu çıkarımda bulunur: "İki su kaynağı da aynı sıcaklıkta olduğu için sahip oldukları ısı enerjisi eşittir". Öğrencinin yaptığı çıkarıma katılıyor musunuz?

Öğrencilerin %75'i bu soruya "evet" cevabı verir.

Öğrencilerin bu cevabı vermelerine neden olan yanılgıyı/düşünceyi yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Isı maddenin içsel özelliklerinden biridir. • Maddelerin ısısı vardır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.14

Bazı kavramlar günlük hayatta bilimsel anlamlarından uzak bir şekilde kullanılmaktadır. Aşağıda bununla ilgili iki örnek verilmiştir:

- Bir termos satıcısı, sattığı termosların iç ve dış yüzeylerinin metalden oluştuğunu söyleyerek reklam yapar.
- Restoran sahipleri evlere gönderim yaparken yemekleri alüminyum folyoyla kaplar.

Bu iki örnek uygulamanın öğrencilerde oluşturabileceği kavram yanılgılarını yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Metaller yalıtkandır. • Metaller sıcaklığı soğurur. • Metal soğuk tutar
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.15

Isıl denge konusunun işlendiği bir fizik dersinde, öğretmen öğrencilere aşağıdaki soruyu sormuştur.

80 derecedeki 500 g sıcak suyla, 40 derecedeki 500 g soğuk karıştırılmıştır. Sıcak ve soğuk suyun sıcaklığı nasıl değişir (artar/azalır/değişmez)? Açıklayınız.

Bir öğrencinin soruya verdiği cevap aşağıdaki gibidir:

Sıcak su ve soğuk su karıştırıldığında hem sıcak suyun hem de soğuk suyun sıcaklığı değişir çünkü sıcak sudan soğuk suya sıcaklık geçişi olur. Bu iki suyun sıcaklığı eşitlenene kadar sıcak suyun sıcaklığı azalır ve soğuk suyun sıcaklığı artar.

Öğrencinin cevabında göze çarpan kavram yanılgısı/yanılgıları nedir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Maddeler arasında sıcaklık geçişi olur.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.16

Emre öğretmen, bir sınıf tartışması sırasında aşağıdaki tabloyu tahtaya çizmiştir.

Madde	A	B
Kütle	2 g	25 g
Öz ısı	$4.0\frac{J}{°C \times g}$	$2.0\frac{J}{°C \times g}$
Sıcaklık	30 °C	30 °C

Öğretmen "A ve B maddeleri ısıca yalıtılmış bir ortamda yan yana gelirse ne olur?" sorusunu sorar ve öğrencilerin tartışmasını ister.

Aşağıdakilerden hangisi öğrencilerin bu soruya verebileceği yanlış cevaplardan biridir? (Birden fazla işaretleme yapabilirsiniz)

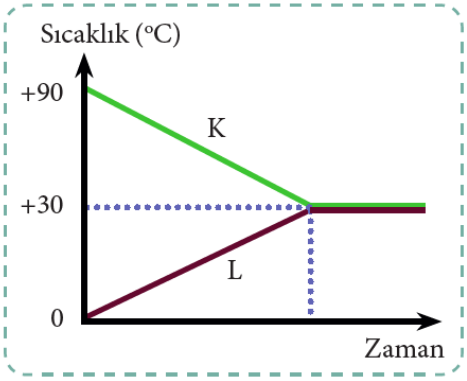
Isı akışı A'dan B'ye doğrudur.	+
Isı akışı B'den A'ya doğrudur.	+
Isı akışı olmaz.	

Öğrencilerin yanlış cevap vermelerine neden olan yanılgılı düşüncelerini yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Maddenin kütlesi, öz ısısı ya da ısı sığası, ısı alışverişinin gerçekleşip gerçekleşmeyeceğini belirleyen faktörlerdendir. • Isı alışverişinin gerçekleşip gerçekleşmeyeceği, maddelerin sıcaklıkları dışındaki faktörlere de bağlıdır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.17

Bir fizik öğretmeni, öğrencilerinden şekildeki grafiği yorumlamasını ister.



Öğrencilerden biri şu yorumda bulunur: "Başlangıçta K cisminin ısısı, L cisminin ısısından daha fazladır. K cisminin ısısı daha fazla olduğu için iç enerjisi de L'den daha yüksektir. Zaman içerisinde K'dan L'ye sıcaklık geçişi olmuş, K'nın sıcaklığı düşmüş ve L'nin sıcaklığı yükselmiştir."

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler nelerdir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Maddelerin ısısı vardır. • İç enerji bir maddenin toplam ısısının ölçüsüdür. • Sıcaklık iletilebilen bir büyüklüktür.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.18

Bir öğretmen, ısı ve sıcaklık konusuna başlarken öğrencilerin ön bilgisini ölçmek için aşağıdaki soruyu sormuştur.

> "Sıcak bir yaz günü Pelin kendisine bir bardak limonata doldurur ve içerisine buz ekler. Pelin, on dakika sonra buzların eridiğini ve limonatanın soğuduğunu fark eder. Sizce limonata nasıl soğumuş olabilir?"

Öğrencilerin bu soruya verebilecekleri muhtemel yanlış cevapları listeleyiniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplar verilir: • Buzdan limonataya soğukluk geçmiştir. • Limonatadan buza sıcaklık geçmiştir. • Limonatadan sıcaklık, buzdan ise soğukluk geçmiştir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.19

Bir fizik dersinde öğrencilerden biri şu yorumda bulunur:

Su ısıtıcısında kaynayan suyun iç enerjisi, buzluktaki buz küplerinin iç enerjisinden daha fazladır çünkü suyun sıcaklığı daha fazladır.

Öğrencinin yorumunda dikkat çeken problemli düşünce nedir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplar verilir: o Öğrenci, iç enerjinin bağlı olduğu diğer bir değişken olan kütleyi dikkate almamıştır. o Öğrenci iç enerjinin yalnızca sıcaklığa bağlı olduğunu düşünmüştür.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.20

Öğrenciler fizik dersinde aşağıdaki hipotezleri oluşturmuştur. Lütfen bu ifadelerin hipotez olup olmadığını belirtiniz.

İfade	Hipotez	Hipotez değil
Su ne kadar çok ısıtılırsa sıcaklığı o kadar artar.	+	
Bir maddenin sıcaklık değişimi pek çok faktöre bağlıdır (?).		+
Bir maddeye verilen ısı miktarı, o maddenin sıcaklığındaki değişimle ilişkilidir.	+	

KSU.21

Ayşe öğretmen, ısı akışını işlediği bir derste bir analoji kullanacaktır. Isı hareketinin yüksek sıcaklıktan düşük sıcaklığa doğru olduğunu ve sıcaklıklar eşitlenene kadar devam ettiğini göstermek için şekildeki düzeneği kurar. İçerisinde fazla miktarda su bulunan tüp yüksek sıcaklığı, az miktarda su bulunan tüp ise düşük sıcaklığı temsil etmektedir (Şekil 1). Tüpler arasındaki geçiş serbest bırakıldığında iki tüpteki sıvı seviyesi eşitlenir (Şekil 2). Ayşe öğretmen, bu gösterimle ısı alışverişi sonucunda cisimlerin sıcaklıklarının eşitlendiği bilgisini, analoji yoluyla öğrencilerine göstermeyi amaçlamıştır.



Şekil 1



Şekil 2

Bu gösterimin, öğrencilerde sebep olabileceği bir kavram yanılgısı yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevap verilir: • Isı sıvı gibi bir maddedir
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.22

Isıl denge konusunun işlendiği bir derste, öğrenciler gruplar halinde etkinlik yapar. Su dolu bir kabın içerisine ısıtılmış çelik vidalar atılır ve sıcaklık değişimleri gözlemlenir. Etkinlik sonrasında öğretmen ve öğrenciler arasında aşağıdaki konuşma gerçekleşir:

Öğretmen: Aranızdan biri ne gözlemlediğini anlatabilir mi?
Elif: Bir vidayı ısıttık ve suyun içerisine attık… Suyun sıcaklığı belirli bir miktar arttı. Daha fazla vida eklediğimizde ise suyun sıcaklığı daha da fazla arttı.
Öğretmen: Tamam… Peki etkinliğin amacı nedir? Ne öğrendiniz?
Ali: Bence sıcak cisimlerin kütlesinin etkisini öğrendik… Çünkü toplam kalorileri daha fazla... Mesela bir vidanın 5 kalorisi olduğunu düşünelim… Böylece, beş vidanın da 25 kalorisi olur.
Ege: Evet, bu yüzden vida sayısı arttıkça su daha çok ısındı.

Yukarıdaki diyalogda göze çarpan kavram yanılgısını belirtiniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Isı maddenin içsel özelliklerinden biridir. • Maddelerin ısısı vardır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğretim Yöntemleri Bilgisi

IS.1

Okulunuzda staj yapan bir fizik öğretmen adayı, ‘öz ısı’ konusu için bir ders planı hazırlayacaktır. Öğretmen adayı, dersi bir öğrenci düşüncesi üzerine kurgulamak ister. Biraz araştırma yaptıktan sonra “bütün metallerin öz ısıları aynıdır” düşüncesine odaklanmaya karar verir. Öğretmen adayı bu düşünce kapsamında tasarlanabilecek deneyler konusunda sizden fikir ister.

Öğretmen adayına önerebileceğiniz basit bir deney tasarlayınız.

Kodlama	Kriter
Doğru (1)	• İki farklı metalin verilen ya da alınan ısıya bağlı olarak sıcaklıklarının değişiminin incelendiği basit bir deney tasarlanır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğretmen adayının dersi yanılgılı düşünceler üzerine kurgulamasının sebepleri neler olabilir? Aklınıza gelen tüm fikirleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Öğrencilerin var olan düşünceleri yeni konularla bağlantı kurmayı sağlar. • Öğrenciler düşüncelerinin doğru olmadığını keşfedip şaşırır ve yeni bilgiler öğrenmeye hazır hale gelir • Öğrencilerin yanılgılı düşünceleri bilimsel olarak doğru düşüncelerle değiştirilmelidir. • Öğrenci anlayışlarının değiştirilmesi çok zordur, iyi öğretim yöntemleri kullanılarak değiştirilebilir (Kirschner et al., 2016).
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.2

Bir fizik öğretmen adayı staj dersinde öğrencilere etkinlik yaptırmak ister. Isı iletimi konusuyla ilgili ilgi çekici bir etkinlik teması oluşturur ve aşağıdaki bilgilendirici metni hazırlar.

Penguenleri kurtar! Kutuplarda yaşayan penguenler küresel ısınma tehdidiyle karşı karşıya. Penguenleri sıcaktan koruyacak evler yapmak istemez misin? Hadi penguenler için bir ev tasarlayalım!

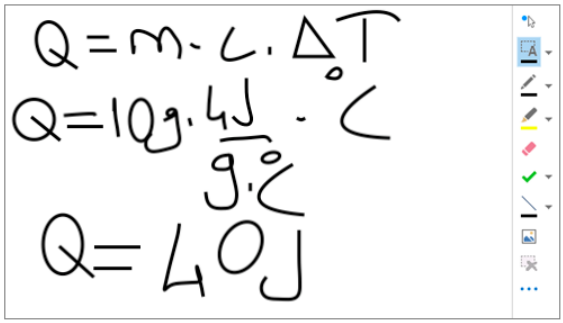
Öğretmen adayı etkinlik kapsamında kullanılacak malzemeleri belirler: Buz parçaları, yün kumaş, termometre

Öğretmen adayının hazırladığı bu etkinlik, bilimsel araştırma basamaklarına daha uygun olacak şekilde nasıl düzenlenebilir? Aklınıza gelen tüm önerileri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Deneye kontrol mekanizması eklenmeli: Hangi ev türünün penguenler için daha yaşanılır olduğunu test etmek amacıyla kontrol değişkeni ya da değişkenleri kullanılmalı.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.3

Bir fizik öğretmeninin çözdüğü problem şekildeki gibidir.



Fizik öğretmeninin hesap yaparken birim kullanmanın önemi ne olabilir? Aklınıza gelen tüm fikirleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Sayılar tek başlarını fiziksel bir büyüklük ifade etmezler, birimle anlam kazanırlar. • Birimler sonuçları anlaşılır ve anlamlı kılar. • Birim kullanmak hataları fark etmeyi kolaylaştırır. • Birimleri sürekli kullanmak hesaplama yapmadan önce dönüştürme yapmaya gerek olup olmadığı konusunda farkındalık uyandırır. • Birimleri kullanmaya alışkın olmak formülleri öğrenmeyi ve bağlantılar kurmayı kolaylaştırır (Kirschner et al., 2016).
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.4

Bir fizik öğretmeni ısı-sıcaklık dersinde şu analojiyi kullanmıştır: “Mısır patlatmak için bir tencereye mısır taneleri eklenir ve ocağın üstüne konur. Süre geçtikçe mısır taneleri tencere içinde hareket etmeye ve tencere kenarlarına çarpmaya başlar.”

Fizik öğretmeni bu analojiyi öncelikli olarak aşağıdaki büyüklüklerden hangisini açıklamak için kullanmış olabilir?

Öz ısı	
Sıcaklık	+
Isı sığası	
Konveksiyon	
Kondüksiyon	

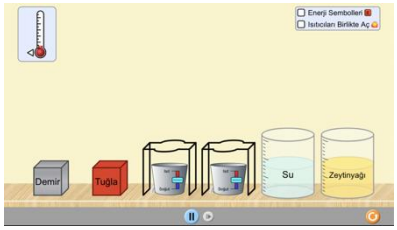
Bu analojinin (benzetmenin) sınırlılıkları ne olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı alan ve sıcaklığı artan maddelerin yapısı değişmez, analojide ısı alan mısırın yapısı değişiyor.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.5

Bir fizik öğretmeni öğrencilerine “90 °C sıcaklığındaki 250 g suyla 10 °C sıcaklığındaki 500 g su karıştırılırsa denge sıcaklığı ne olur?” sorusunu sorar. Öğretmen sorunun araştırılması için iki alternatif yöntem belirler. Bu yöntemlerden ilkinde gerçek laboratuvar malzemeleri kullanılmaktadır (Şekil 1). İkinci yöntemde ise sanal laboratuvar (simülasyon) kullanılmaktadır (Şekil 2).





Öğretmenin sorduğu soru bağlamında düşündüğünüzde, ikinci yöntemin birinci yönteme kıyasla sahip olduğu avantajlar neler olabilir?

Kodlama	Kriter

Doğru (1)	Aşağıdaki cevaplardan biri verilir:
	• Isıl dengenin gerçekleşmesi için gereken süreyi azaltmak
	• Parametreleri değiştirme kolaylığı
	  ○ Çok yüksek ve çok düşük sıcaklıklarla çalışabilmek
	  ○ Deneyi farklı sıcaklıktaki sıvılar için tekrarlayabilmek
	• Isı yalıtım eksikliğinden vb. kaynaklanan karıştırıcı değişkenlerin etkisini engellemek
	• Yüksek sıcaklıklarla çalışılmadığı için daha güvenli ve daha az riskli

Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir YA DA deneyle ilişkilendirmeden genel cevaplar verilir: • Daha güvenli • Daha kolay • Az risk • Daha doğru sonuçlar verir
Boş (0)	Soru cevapsız bırakıldı.

IS.6

Bir fizik dersinde, öğretmen adayı, buzdolabında yeterince beklemiş çinko ve platin parçaları örneğiyle derse giriş yapar. Öğrencilerden maddeleri gözlemlemelerini ve yorumda bulunmalarını ister. Mert aşağıdaki yorumu yapar:

Çinko parçaları, platin parçalarına göre daha soğuk hissettirdi. Bunun sebebi çinkonun öz ısısının (0.5 kj/kg.C) platinin öz ısısından (0.13 kj/kg.C) daha yüksek olması. Yani çinkonun 1 gramının sıcaklığını artırmak için gereken ısı miktarı, platine göre daha fazla.

a. Fizik öğretmen adayı Mert'in açıklamasını nasıl değerlendirmelidir?

1. Mert doğru bir açıklama yaptı ( )
2. Mert eksik/yanlış bir açıklama yaptı ( )

b. Fizik öğretmen adayı bir sonraki adım olarak aşağıdaki uygulamayı yaptırmayı planlar.

Öğrenciler çinko ve platin parçalarını ısıtırlar. Verilen ısıya bağlı olarak sıcaklık değişiminin gösterildiği bir grafik çizerler.

Öğretmen adayının yerinde siz olsaydınız bir sonraki adım olarak yukarıdaki aktiviteyi kullanır mıydınız?

1. Evet ( )
2. Hayır ( )

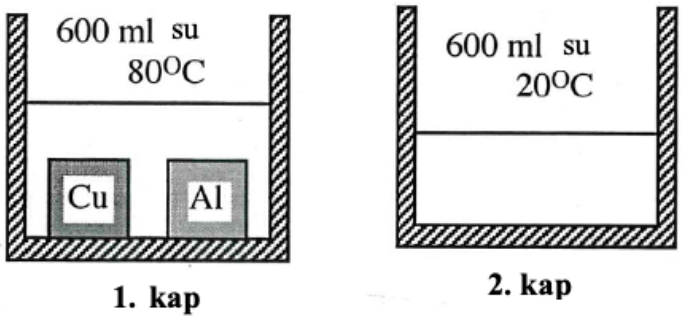
Cevabınız evetse, bu aktivite öğrencilerin anlayışlarını güçlendirmeye nasıl yardımcı olabilir?

Cevabınız hayırsa, bu aktivite nasıl düzenlenebilir ya da farklı hangi aktiviteler kullanılabilir?

Kodlama Şeması	
Kodlama	Kriter
Doğru (1)	• "a" bölümünde 2, "b" bölümünde 2 işaretlenir. ve aşağıdaki gibi bir açıklama yapılır: • Çocuklar öz ısıyla ilgili değil de ısı iletkenliğiyle ilgili deneyler yapmalı. Bunun için öz ısısı büyük fakat ısı iletkenliği küçük bir maddeyle, öz ısısı küçük fakat ısı iletkenliği büyük bir maddenin kullanıldığı deneyler yapılabilir. Böylece öğrenciler ısı iletkenliğinin öz ısıyla ilgili olmadığını görmüş olur.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.7

Bir fizik öğretmen adayı öğrencilerine aşağıdaki örneği verir.



Su dolu bir kapta bakır ve alüminyum blokları ısıl dengededir. Bakırın ısı sığası 200 cal/C ve alüminyumun ısı sığası 100 cal/C'dir. Birinci kaptaki bloklar ikinci kaba aktarılır ve ısıl dengenin gerçekleşmesi beklenir. Bloklarda gerçekleşen sıcaklık değişimleri nasıl olur?

Öğrencilerden Melike şu yorumu yapar:

Bakır bloktaki sıcaklık değişimi alüminyuma göre daha fazladır çünkü bakırın ısı sığası alüminyumdan daha fazladır.

a. Fizik öğretmen adayı Melike'nin açıklamasını nasıl değerlendirmelidir?

3. Melike doğru bir açıklama yaptı ( )
4. Melike eksik/yanlış bir açıklama yaptı ( )

b. Fizik öğretmen adayı bir sonraki adım olarak aşağıdaki uygulamayı yaptırmayı planlar.

Öğrenciler bir termometre yardımıyla bakır ve alüminyum bloklardaki sıcaklık değişimini inceler. Sıcaklık değişiminin zamana bağlı grafiğini çizerler.

Öğretmen adayının yerinde siz olsaydınız bir sonraki adım olarak yukarıdaki aktiviteyi kullanır mıydınız?

3. Evet ( )
4. Hayır ( )

Cevabınız evetse, bu aktivite öğrencilerin anlayışlarını güçlendirmeye nasıl yardımcı olabilir?

Cevabınız hayırsa, bu aktivite nasıl düzenlenebilir ya da farklı hangi aktiviteler kullanılabilir?

Kodlama	Kriter
Doğru (1)	• a bölümünde 2, b bölümünde 1 işaretlenir. ve aşağıdaki gibi bir açıklama yapılır: • Isıl denge sonunda tüm maddeler eşit sıcaklıkta olur. Isıl dengeye ulaşan cisimlerin sıcaklık değişimiyle ısı sığaları arasında bir ilişki yoktur. Öğretmenin seçtiği uygulama belirli bir süre geçtikten sonra iki blokta da eşit miktarda sıcaklık değişimi olduğunu göstermesi açısından önemlidir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.8

Isı ve sıcaklıkla ilgili büyüklüklerin tartışıldığı bir fizik dersinde, öğrencilerden biri şu yorumda bulunur:

Soğuk kış günlerinde parka gittiğimizde metal banklar yerine tahta banklara oturmak isteriz. Çünkü metal banklar tahta banklardan daha soğuktur, bu yüzden bizi üşütür.

Fizik öğretmeninin yerinde siz olsaydınız, öğrencinin yanılgılı düşüncesini düzeltmek için nasıl bir yöntem izlerdiniz?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Öğretmen öğrencinin yanılgılı düşüncesine değinir ve kavramsal bir yaklaşım benimser. Bilimsel olarak doğru düşüncenin oluşması için çeşitli bilimsel uygulamalar yaptırır. • Öğrencinin sahip olduğu kavram yanılgısı belirtilir,
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.9

Bir öğrenci maddelerin soğuma hızının hacme ve yüzey alanına bağlı olduğunu düşünür ve bir deney tasarlar. Deneyde aşağıdaki iki farklı su deposunun soğuma hızlarını inceler.

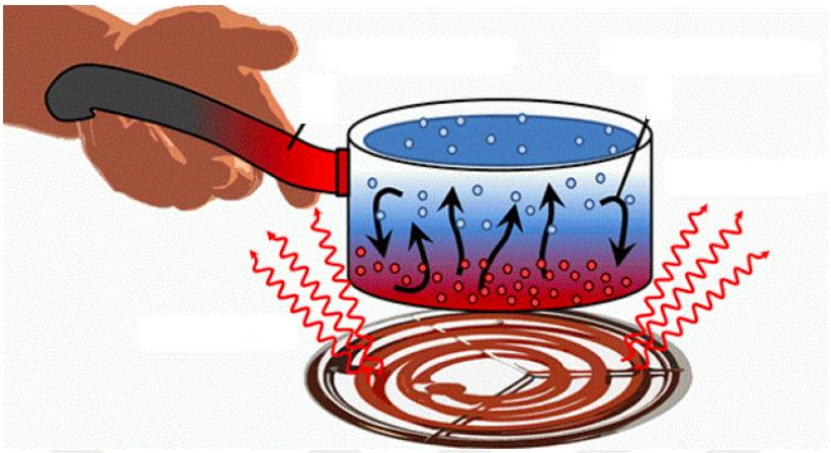
 Yüzey alanı=6m^2 Hacim=2m^3	 Yüzey alanı=5m^2 Hacim=3m^3

Öğrencinin tasarladığı deneyde ihmal ettiği bilimsel uygulama özelliğini yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • İki değişken aynı anda inceleniyor (hacim ve yüzey alanı); bir deney sırasında yalnızca tek bir faktör değiştirilebilir ve diğer değişkenler sabit tutulmalıdır. • Farklı yüzey alanına sahip depolardaki soğuma hızı eşit şartlar altında (aynı hacme sahip depolarda) karşılaştırılmalıdır. • Farklı hacme sahip depolardaki soğuma hızı eşit şartlar altında (aynı yüzey alanına sahip depolarda) karşılaştırılmalıdır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.10

Emre öğretmen, ısı ve sıcaklık ünitesini işlediği bir derste aşağıdaki gösterimi kullanmıştır.



Emre öğretmenin, bu gösterimi kullanarak öğrencilerin öğrenmesini hedeflediği kavramları/bilgileri listeleyiniz.

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevaplardan üçü verilir: • Enerji iletim yolları (Kondüksiyon, konveksiyon, radyasyon)
Kısmen doğru (1)	Aşağıdaki cevaplardan ikisi ya da biri verilir: • Enerji iletim yolları (Kondüksiyon, konveksiyon, radyasyon)
Yanlış/ilgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.11

Katıların ısı iletimini işlediğiniz bir derste, bilimsel araştırma basamaklarını vurgulamak istiyorsunuz. Derste izlenecek adımlardan ve deneysel aşamalardan oluşan bir taslak hazırladınız.

Aşağıdaki tabloda eksik olan ders içi adımları ve deneysel aşamaları tamamlayınız.

Ders İçi Adımlar	Deneysel Aşama
Soğuk bir kış gününde, alüminyumdan yapılmış bir bank, pirinçten yapılmış bir banka göre daha soğuk hissettirir.	Gözlem
Hangi materyal ısıyı daha iyi iletir?	(A)
(B)	Hipotez oluşturma
Alüminyum ve pirinçten yapılmış iki farklı bardaktaki suya eşit miktarda ısı verilir.	(C)
İki bardaktaki suyun sıcaklık değişimi raporlanır ve grafik oluşturulur.	(D)
Alüminyum bardaktaki suyun sıcaklık değişimi, pirinç bardaktaki suyun sıcaklık değişiminden daha fazladır.	(E)
(F)	Sonuç

	Kriter		
Kodlama	(A)	(B)	(C)
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Problem oluşturma • Araştırma sorusu sorma	Aşağıdaki cevaplardan biri verilir: • Alüminyum ısıyı pirinçten daha iyi iletir. • Alüminyum daha iyi bir iletkendir.	Aşağıdaki cevaplardan biri verilir: • Deney planlama
Yanlış/İlgisiz (0)	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.
Boş (0)	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.

	Kriter		
Kodlama	(D)	(E)	(F)
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Veri toplama • Ölçüm yapma	Aşağıdaki cevaplardan biri verilir: • Veri analizi • Verileri değerlendirme • Değerlendirme	Aşağıdaki cevaplardan biri verilir: • Alüminyum ısıyı pirinçten daha iyi iletir. • Alüminyum daha iyi bir iletkendir.
Yanlış/İlgisiz (0)	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.	Cevap, yukarıda belirtilen noktalardan hiçbirini yansıtmamaktadır.
Boş (0)	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.

	Doğru sayısı	Kodlama
Puan	6	2
	5	
	4	1
	3	
	2	0
	1	
	0	

IS.12

Fizik dersinde yapılabilecek deneylerden oluşan bir kitapta, aşağıdaki aktivite önerisi yer almaktadır:

> Boş bir cam şişenin ucuna balon takılır ve şişe geniş bir kaba yerleştirilir. Kaba sıcak su dökülür ve balonun zamanla şiştiği görülür.

Bu aktivite kitapta deney olarak adlandırılmıştır fakat gerçek bilimsel deney özelliklerini yansıtmamaktadır. Bunun sebebi ne olabilir? Aklınıza gelen tüm düşünceleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Bir değişkenin diğer değişken üzerindeki etkisi ölçülmüyor ve raporlanmıyor. • Deney farklı sıcaklıklardaki su ile tekrarlanmıyor.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.13

Fizik dersinde yapılabilecek deneylerden oluşan bir kitapta, aşağıdaki aktivite önerisi yer almaktadır:

> Bir kavanoza su doldurulur ve sınıfın güneş alan bir bölgesine konulur. Öğrenciler günden güne suyun seviyesinin nasıl değiştiğini not ederler.

Bu aktivitede, deneyden ziyade hangi bilimsel araştırma basamağının kullanıldığını belirtiniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevap verilir: • Gözlem
Yanlış/İlgisiz (0)	Farklı bilimsel araştırma basamakları söylenir YA DA Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.14

Bir fizik öğretmeni ısı sıcaklık dersinde şu analojiyi kullanmıştır: “İşçiler, kum torbalarını üst üste dizip bir duvar yaparlar. Bazı işçiler diğerlerinden daha dayanıklıdır; çok fazla yorulmadan uzun bir süre boyunca kum torbalarını taşıyıp duvar oluşturabilir. Bir kısım işçi ise çok hızlı çalışabilir. Fakat hızlı çalışıyor olmaları, uzun süre boyunca çalışabildikleri anlamına gelmez.”

Fizik öğretmeni, kullandığı analojide kum torbalarından oluşan duvarı “tranfer edilen ısı”ya benzetmiştir. Bu örnekte benzetimi yapılan diğer büyüklükler aşağıdakilerden hangisi olabilir?

Öz ısı-İç enerji	
Isı sığası-İç enerji	
İç enerji-İletkenlik	
Isı sığası-İletkenlik	+

Kodlama	Kriter
Doğru (1)	Yalnızca “Isı sığası-İletkenlik” seçeneği işaretlenir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.15

Bir fizik öğretmeni derste şekildeki gösterimi yapar. Su ile dolu plastik bir kap içerisine mavi gıda boyası ile renklendirilmiş buz ve kırmızı gıda boyası ile renklendirilmiş sıcak su ekler ve öğrencilerden suyu gözlemlemelerini ister.



Şekil

Öğretmen aşağıdaki aktivitelerden hangilerini açıklamak için bu gösterimde bulunmuş olabilir?/ Öğretmen bu gösterimi kullanarak aşağıdaki olayların hangilerini açıklamak istemiş olabilir? Birden fazla işaretleme yapabilirsiniz.

Magma sıvısının hareketi	+
Donmuş etin çözünmesi	+
Mumun yanması	
Sıcak hava balonlarının çalışması	+
Mikrodalga fırının çalışması	
Meltem rüzgarlarının oluşması	+
Soba yakılan bir odanın ısınması	+

Kodlama	Kriter
Doğru (1)	3, 4 ya da 5 doğru seçim yapılmıştır.
Yanlış/İlgisiz (0)	2, 1 ya da 0 doğru seçim yapılmıştır.
Boş (0)	Soru cevapsız bırakıldı.

IS.16

Bir fizik dersinde ısı, öz ısı ve ısı sığası terimlerini öğrencilere tanıttınız. Bu üç kavram arasındaki bağlantıları ve farklılıkları vurgulamak istiyorsunuz.

Öğrencilere 100 kalori, 100 Cal/g^{o}C ve 100 cal/°C arasındaki farkı nasıl açıklarsınız? Bu üç büyüklük arasındaki bağlantıları vurgulayan ve öğrenciler için anlamlı olabilecek örnekler veriniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki bağlantılardan ikisi verilir. • Bir cismin sıcaklığını arttırmak için o cisme 100 kalori ısı verilir. Bu 100 kalori, öz ısısı 100 Cal/g^{o}C olan 1 gram ağırlığındaki cismin sıcaklığını 1 derece arttırır. Isı sığası 100 cal/°C olan bir cismin sıcaklığını 1 derece arttırmak için verilmesi gereken ısı miktarı da 100 kaloridir. • Isı- öz ısı arasındaki bağlantı: Öz ısısı 100 Cal/g^{o}C olan 1 gram ağırlığındaki bir cismin sıcaklığını 1 derece arttırmak için verilmesi gereken ısı miktarı 100 kaloridir. • Isı- ısı sığası arasındaki bağlantı: Bir cismin sıcaklığının 1 derece azalması için cismin vermesi gereken ısı miktarıdır. • Öz ısı-ısı sığası arasındaki ilişki: Bir cismin sıcaklığını 1 derece arttırmak için verilmesi gereken ısı miktarı ısı sığasını ifade ederken, aynı cismin 1 gramının sıcaklığını 1 derece arttırmak için verilmesi gereken ısı miktarı öz ısıyı ifade eder.
Yanlış/İlgisiz (0)	• Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.17

Bir fizik öğretmen adayı, ısı ve sıcaklık ünitesi kapsamında öğrencilere bir deney yaptıracaktır. Deneyde kullanılan malzemeler ve deneyin yapılışı şu şekildedir:

Malzemeler: 2 adet siyah kumaş parçası, 2 adet beherglas, streç film, termometre, ışık kaynağı

Deneyin yapılışı:

1. Kumaş parçaları beherglaslar içine yerleştirilir ve bir beherglasın ağzı streç film ile kapatılır.
2. İki beherglas içindeki kumaş parçalarının ilk sıcaklıkları ölçülür.
3. Işık kaynağı kullanılarak beherglaslara ısı verilir.
4. Bir süre sonra beherglasların içindeki kumaş parçalarının sıcaklıkları ölçülerek karşılaştırılır.

Fizik öğretmen adayının tasarladığı bu deneyin amacı ne olabilir? Açıklayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Küresel ısınmanın sebeplerinden birinin sera etkisi olduğunu göstermek • Sera etkisinin Dünya sıcaklığını artırdığını göstermek
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.18

Bilişsel çelişki, kişilerin düşünceleri ile gerçek hayatta karşılaştıkları durumlar arasında var olan uyumsuzluktur.

Örnek:

Bir fizik dersinde öğrenciler 0 derecedeki suya buz ekler ve suyun sıcaklık değişimini zamana bağlı olarak not ederler. Öğretmen, aktivite sonrasında öğrencilerde bilişsel çelişki yaşandığını fark eder.

Aşağıdakilerden hangisi, bilişsel çelişki yöntemini kullanmak isteyen bir öğretmenin kullanabileceği aktivitelerdendir? Birden fazla işaretleme yapabilirsiniz.

Bir buz parçasını yünle kaplayıp sıcaklık değişimini ölçmek	+
İçerisine sıcak bir metal kaşık konulan suyun sıcaklık değişimini ölçmek	
Soğuk bir kış gününde, parktaki metal ve tahta bankların sıcaklıklarını ölçmek	+
Donmuş zeytinyağı ve buzun erimeye başladıkları sıcaklıkları karşılaştırmak	

Kodlama	Kriter
Doğru (2)	2. ve 4. seçenekleri işaretlememek VE 1. ve 3. seçenekleri işaretlemek
Kısmen doğru (1)	2. ve 4. seçenekleri işaretlememek VE 1. ya da 3. seçenekleri işaretlemek
Yanlış/ilgisiz (0)	2. ya da 4. seçeneklerden birini ya da ikisini işaretlemek.
Boş (0)	Soru cevapsız bırakıldı.

IS.19

Bir fizik öğretmeni öğrencilerine aşağıdaki aktiviteyi yaptırır.

> Üç farklı kavanoza sıcak su, soğuk su ve oda sıcaklığında su konur. Kavanozlara birer damla gıda boyası damlatıldığında, sıcak sudaki boyanın soğuk sudaki boyaya göre daha hızlı yayıldığı görülür.

Öğretmen bu aktivite ile öğrencilerin hangi çıkarımı yapmasını/hangi sonuca ulaşmasını istemiş olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı alan maddelerin taneciklerinin hızı artar. • Maddeler sıcakken taneciklerinin hızı daha fazladır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.20

Bir fizik öğretmeni birbirine alternatif olabilecek iki farklı aktivite belirler ve derste kullanmaya karar verir.

1.aktivite: Bir balon muma dokundurulur ve yanmaya başlar. Aynı balonun içine su doldurulur ve tekrar muma dokundurulur. Balonun yanmadığı gözlenir.

2.aktivite: Kağıt bir para muma dokundurulur ve yanmaya başlar. Aynı kağıt para bakır bir çubuğa sarılıp muma dokundurulduğunda yanmaz.

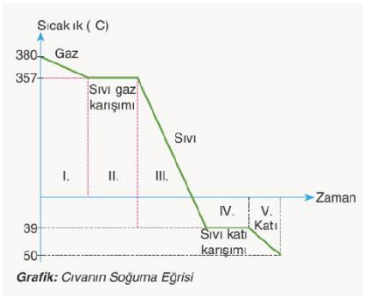
Öğretmen aktiviteleri yapan öğrencilerin hangi kavramları/bilgileri öğrenmesini hedeflemiş olabilir? Listeleyiniz.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı iletimi
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Program Bilgisi

KC.1

Dokuzuncu sınıfa yeni başlamış bir öğrenci aşağıdaki içeriklerden hangisini/hangilerini daha önce hiç görmemiş olabilir?



Grafik: Cıvanın Soğuma Eğrisi

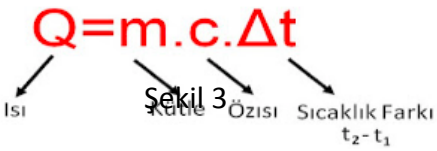
Şekil 1

Tablo: Bazı Maddelerin Öz Isıları

Madde	Öz Isı (J/g°C)
Bakır	0,37
Alüminyum	0,90
Çinko	0,39
Kurşun	0,13
Nikel	0,45
Demir	0,46

Kaynak: Beichner, Serway, Fen ve Mühendislik İçin Fizik 1

Şekil 2



Şekil 3

Soru: 15 metre uzunluğundaki bir bakır tel 40 °C den -9°C dereceye soğutulmuştur. Boy değişimi nekadar olur?

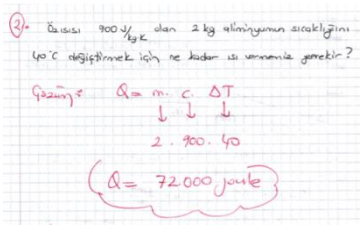
- Cevap: Cu için $\alpha_\ell = 16.5 \times 10^{-6}\ (°C)^{-1}$

Şekil 4

Şekil 1	
Şekil 2	
Şekil 3	+
Şekil 4	+

KC.2

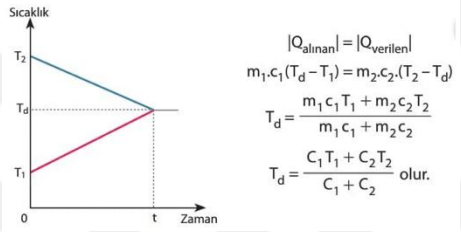
Dokuzuncu sınıfı bitirmiş bir öğrenci aşağıdaki içeriklerden hangisini/hangilerini daha önce görmüş olabilir?



Şekil 1

Kütlesi m, öz ısısı c olan bir cisme Q kadar ısı verildiğinde sıcaklığındaki değişim T oluyor. **Buna göre aynı cins malzemeden yapılmış 2m kütleli bir başka cisme 4Q kadar ısı enerjisi verilirse sıcaklığındaki değişim kaç T olur?**

Şekil 2

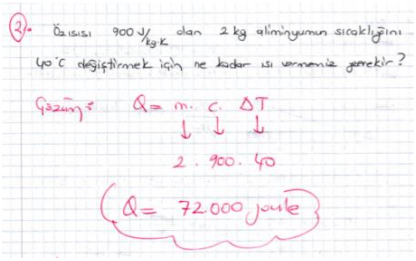


Şekil 3

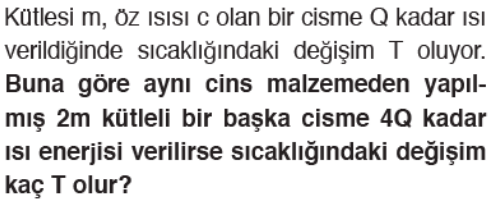
Şekil 1	
Şekil 2	+
Şekil 3	

KC.3

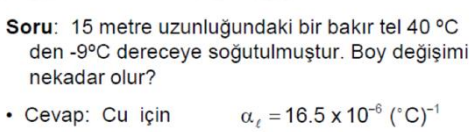
Aşağıdaki içeriklerden hangilerini son 15 yılda liselerde fizik dersi almış öğrencilerin tamamı görmüş olabilir? Birden fazla işaretleme yapabilirsiniz.



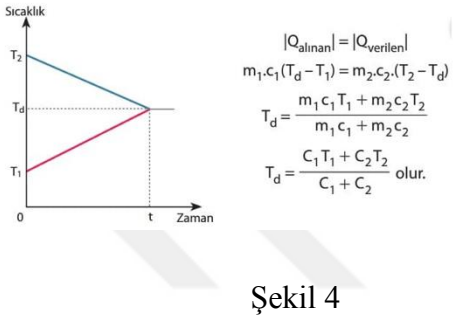
Şekil 1



Şekil 2



Şekil 3



Şekil 4

Şekil 1	
Şekil 2	+
Şekil 3	
Şekil 4	

KC.4

Etkinlik 1: Öğrenciler farklı cins katı maddelerin ısı iletim hızlarını karşılaştırır.
Etkinlik 2: Öğrenciler kalorifer tarafından ısıtılan havanın oda içerisindeki döngüsünü modeller.
Etkinlik 3: Öğrenciler ısınma problemi olan bir evin yalıtımını artırmaya yönelik bir proje geliştirir.
Etkinlik 4: Öğrenciler yalıtımı artıracak alternatif çözüm önerileri için bütçe hesaplamaları yapar.
Etkinlik 5: Öğrenciler ısı yalıtımı kullanılan bir evle kullanılmayan bir evin ısınma giderlerini karşılaştırır.
Etkinlik 6: Öğrenciler farklı renk binaların ısı yalıtımlarını karşılaştırır.

Öğretim programında belirtilen prensipler göz önünde bulundurulduğunda, ısı iletim hızının işlendiği derslerde öncelikli olarak yaptırılabilecek aktiviteler hangileridir?

Etkinlik 1	+
Etkinlik 2	+
Etkinlik 3	+
Etkinlik 4	+
Etkinlik 5	+
Etkinlik 6	

KC.5

Bir fizik öğretmeni resimdeki Gravzant halkasını derste kullanır.

Fizik öğretmeni bu materyali hangi konuyu/ alt konuyu anlatmak için kullanmış olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Genleşme • Katıların genleşmesi
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğretmenin yerinde siz olsaydınız bu materyalin kullanıldığı dersin kazanımı ne olurdu?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevap verilir: • Öğrenciler ısı alan katı maddelerin genleştiklerini gözlemler.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KC.6

Aşağıdakilerden hangileri öğrencilerin iç enerji kavramını anlamaları için bilmeleri gereken ön bilgilerdir/kavramlardır/büyüklüklerdir? (Birden fazla işaretleme yapabilirsiniz).

Güç	
İletkenlik	
Kinetik enerji	+
Potansiyel enerji	+
Çekim kuvveti	+

Kodlama	Kriter
Doğru (1)	C, D ve E şıklarının tamamı seçilir
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir şık seçilir.
Boş (0)	Soru cevapsız bırakıldı.

KC.7

2017-2018 döneminde fizik öğretim programında yapılan değişiklikleri göz önünde bulundurduğunuzda ısı sıcaklık ünitesinin hangi alt konularında diğerlerine oranla daha az sadeleştirme gerçekleşmiştir?

a. Isıl denge
b. Genleşme
c. Hal değişimi
d. Enerji iletim yolları (X)

KC.8

Fizik öğretim programında 2007-2008, 2013-2014 ve 2017-2018 dönemlerinde bazı değişiklikler yapıldı. Hangi alanda en az değişim yaşandığı söylenebilir?

a. Matematiksel hesaplamalar
b. Ölçme değerlendirme yaklaşımı (X)
c. Türk İslam bilim insanlarına yapılan vurgu
d. Adalet, öz denetim ve sorumluluk gibi değerlere yapılan vurgu

KC.9

Aşağıdaki aktivitelerinden hangisinin ilk kez 2018 öğretim programında vurgulandığı söylenemez?

a. Öğrencilerden ısı iletim yollarının anlatıldığı karikatürler tasarlamalarını istemek
b. Resim öğretmeniyle birlikte ısı transferinin kullanıldığı özel bir boyama tekniğini tanıtan ders planlamak
c. Farklı enerji kaynaklarının kullanımı ve küresel ısınmaya yönelik sosyobilimsel olaylarla ilgili çıkarım yapmak
d. Küresel ısınmanın tehlikeli boyutlarda olmadığını iddia eden bilim adamlarının bulgularını tartışmak (X)

KC.10

Hangi yıl yayınlanan öğretim programının etkinlik önerileri ve derste kullanılan öğretim stratejileri gibi konularda daha detaylı olduğu söylenebilir?

a. 1997
b. 2007 (X)
c. 2013
d. 2017

KC.11

İki farklı 9. sınıf konu anlatım kitabındaki ünitelerin sıralaması aşağıdaki gibidir:

1. Kitap: Fizik bilimine giriş, madde ve özellikleri, ısı ve sıcaklık, kuvvet ve hareket, enerji, elektrostatik

2. Kitap: Fizik bilimine giriş, madde ve özellikleri, kuvvet ve hareket, enerji, ısı ve sıcaklık, elektrostatik

Sizce hangi kitaptaki sıralama daha uygundur?

1. Kitap	
2. Kitap	+

Seçtiğiniz kitaptaki sıralamanın diğer kitaba kıyasla sahip olduğu avantajlar neler olabilir? Aklınıza gelen tüm fikirleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı ve sıcaklık konusunda, madde taneciklerinin sahip olduğu hız ve enerji gibi büyüklüklerden bahsedilir. Öğrencilerin ısı-sıcaklık konusunu kavrayabilmesi için hız ve enerji kavramlarını bilmesi gerekir. • İç enerji kavramı, tanecik ve potansiyel enerjileriyle ilişkilidir.
Yanlış/ İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

APPENDIX G

TABLE OF SPECIFICATIONS OF THE COMPREHENSIVE ITEM POOL

Table G1. Table of Specifications for Knowledge of Student Understanding dimension

		Items
Sub-topics	Heat and temperature	2, 3, 6, 13, 15, 17, 20, 22
	Heat conduction	4, 8, 12, 14
	Change of state	7, 10, 11
	Heat equilibrium	1, 16, 18, 21
	Internal energy	17, 19
	Thermometer	5, 9
Alternative conceptions and difficulties	Substances possess heat.	7, 13, 17, 22
	Heat is a substance.	21
	Temperature can flow.	15, 17
	Interal energy is a measure of total heat of a substance.	17
	Metals are insulators.	8, 12, 14
	Heat transfers between objects of same temperature.	16
	The temperature of any substance that is heated increases.	7
	Metals are cold.	2, 4
	Objects with higher temperature always transfer more heat.	3
	Temperature values can have multiples on the Celcius thermometer.	5
	Substances given the same amount of heat will have the same final temperature.	6
	Wool warms people.	8
	The melting temperature of a substance depends on its amount.	10
	The amount of heat given substances does not effect its temperature change.	10
	Internal energy depends only on temperature.	19
	Difficulty in applying the experimental procedure (not waiting long enough)	1
	Difficulty in understanding the scaling of the thermometer	9
	Difficulty in formulating hypothesis	20

Table G2. Table of Specifications for Knowledge of Instructional Strategies Dimension

		Items
Sub-topics	Heat and temperature	3, 4, 9, 16, 17, 18, 19
	Heat conduction	2, 6, 7, 8, 11, 14
	Heat transfer	10, 15, 20
	Heat equilibrium	5
	Change of state	12, 13
	Specific heat	1
Instructional strategies	Experiment	1, 2, 9, 11, 17
	Direct instruction	16
	Unit	3
	Demonstration	6, 7, 8, 10, 12, 13, 15, 18, 19, 20
	Analogy	4, 14
	Simulation	5

Table G3. Table of Specifications for Knowledge of Curriculum Dimension

Sub-topic	Items
Heat and temperature	1, 2, 3, 7, 8, 9, 10, 11
Heat conduction	4
Heat transfer	5
Internal energy	6

APPENDIX H

THE EXPERT OPINION DOCUMENT

Uzman Görüşü Formu

Sayın Uzman,

Tez çalışmam kapsamında fizik öğretmenlerinin ısı ve sıcaklık konusuyla ilgili pedagojik alan bilgilerini ölçen bir test geliştirmekteyim. Geliştirmeyi hedeflediğim testin alt boyutları şu şekildedir: Öğrenci anlayışlarına yönelik bilgi, öğretim yöntemleri bilgisi ve program bilgisi. Bu dokümanda belirtilen pedagojik alan bilgisi boyutlarını ölçmeyi hedefleyen sorular yazılmıştır.

Buna göre lütfen,

1. Isı ve Sıcaklık-Pedagojik Alan Bilgisi Testi dosyasında bulunan soruları inceleyerek pedagojik alan bilgisi alt boyutlarına göre belirtke tablosunda kodlayınız.

2. Isı ve Sıcaklık- Pedagojik Alan Bilgisi Testi soruları hakkında görüş ve önerilerinizi yazmak üzere ayrı bir bölüm oluşturulmuştur. Çıkarılmasını ya da geliştirilmesini uygun gördüğünüz soruları lütfen belirtiniz.

3. Isı ve Sıcaklık- Pedagojik Alan Bilgisi Testi'nin cevapları için kodlama şemaları oluşturulmuştur. Kodlama şemalarıyla ilgili görüş ve önerilerinizi yazmak üzere ayrı bir bölüm oluşturulmuştur. Lütfen kodlama şemalarının doğruluğunu kontrol ediniz. Gerekli değişiklikleri ya da eklemeleri bu bölüme yazınız.

Vakit ayırdığınız için teşekkür ederim.

Havva Sağlam

	PEDAGOJİK ALAN BİLGİSİ BOYUTLARI		
Soru	Öğrenci anlayışlarına yönelik bilgi	Öğretim yöntemleri bilgisi	Program bilgisi
1			
2			
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Soru	Sorularla ilgili görüş, öneriler ve eklemeler
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Soru	Kodlama şemalarıyla ilgili görüş ve öneriler
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APPENDIX I

THE PCK-H&T TEST

Değerli öğretmenim,

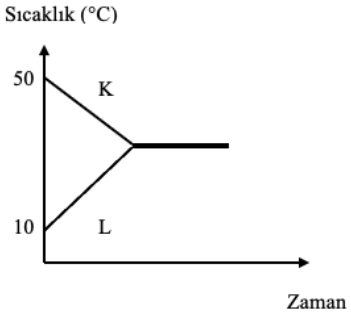
Elinizdeki anket ısı-sıcaklık konusuyla ilgili öğrenci anlayışları ve öğretim yöntemleri hakkındaki düşüncelerinizi incelemektedir. Anket iki bölümden oluşmaktadır. Ankette açık uçlu ve kapalı uçlu sorular bulunmaktadır. Lütfen her soruya cevap vermeye gayret ediniz.

Teşekkür ederim.

Yaş: Öğretmenlik deneyimi: ___ yıl Cinsiyet: K( ) E ( ) Öğrenim durumu: Lisans ( )Yüksek lisans ( )Doktora ( )

1.BÖLÜM: Bu bölümde ısı-sıcaklık konusuyla ilgili öğrenci anlayışlarına yönelik sorular bulunmaktadır.

1. Bir fizik öğretmeni, öğrencilerinden şekildeki grafiği yorumlamasını ister.



Öğrencilerden biri şu yorumda bulunur: “Başlangıçta K cisminin ısısı, L cisminin ısısından daha fazladır. K cisminin ısısı daha fazla olduğu için iç enerjisi de L’den daha yüksektir. Zaman içerisinde K’dan L’ye sıcaklık geçişi olmuş, K’nın sıcaklığı düşmüş ve L’nin sıcaklığı yükselmiştir.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

2. Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar.

“Ayşe ve Ahmet soğuk bir kış gününde evlerinin bahçesini temizler. Ayşe tahta saplı bir süpürge kullanırken, Ahmet metal saplı bir süpürge kullanır. Ayşe bahçeyi sorunsuz bir şekilde süpürürken, Ahmet ellerinin üşüdüğünü hisseder. Ahmet’in böyle hissetmesinin temel nedeni ne olabilir?”

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanlış cevapları sıralayınız.

3. Bir öğrenci ısı-sıcaklık grafiğini şöyle yorumlar:

“Maddeye verilen ısı ile maddenin sıcaklığı arasında bir ilişki var. Cıvaya verilen ısı miktarı arttıkça cıvanın sıcaklığı da artıyor. Örneğin 1. saniyedeki cıva sıcaklığı 42 °C iken 5. saniyede 84 °C oluyor. Yani dört saniye sonunda maddenin sıcaklığı iki katına çıkıyor.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

4. Yoğunlaşma olayının işlendiği bir derste, öğretmen öğrencilere aşağıdaki soruyu sorar.

“Oda sıcaklığındaki bir kavanoz içerisine bir miktar buzlu su konur. 15 dakika sonra kavanozun etrafının ıslak olduğu gözlemlenir. Kavanozun etrafında ıslaklık oluşmasının sebebi nedir?”

Öğrencilerin bu soruya verebilecekleri muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

5. Bir fizik öğretmeni öğrencilerine aşağıdaki tartışma sorusunu sorar.

Hilal, buzdolabından bir şişe meyve suyu ve bir şişe soda çıkarır. Şişeleri masanın üzerinde 20 dakika boyunca bekletir. Meyve suyu ve soda şişelerinin yirmi dakika sonunda eşit miktarda ısı aldığı bilindiğine göre, bu süre sonunda hangi nicelikleri kesinlikle aynıdır?

(A) İç enerji değişimleri (B) Sıcaklıkları (C) İç enerjileri

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevap şıkları neler olurdu?

A ( ) B ( ) C ( )

Öğrencilerin yanlış cevap vermesine neden olabilecek yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

6. Öğrenciler bir fizik dersinde bir etkinlik yapar. Köpük ve alüminyum olmak üzere iki farklı bardağa su dökerler. Bardakları özdeş ısıtıcılarla ısıtıp zamanla bardaklardaki suların sıcaklık değişimini ölçerler. Bulguları doğrultusunda hangi bardağın daha iyi ısı yalıtımlı olduğunu açıklarlar.

Öğretmen deney sonunda öğrencilere şu soruyu sorar: "Bir sodayı soğuk tutmak için hangi malzemeden yapılmış bir kap kullanılmalıdır?" Öğrencilerin %75'i köpük yerine alüminyum cevabını verir.

Soruya yanlış cevap veren öğrencilerin yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

7. Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar.

80 °C'deki 500 g sıcak suyla, 40 °C'deki 500 g soğuk su karıştırılmıştır. Sıcak ve soğuk suyun sıcaklığı nasıl değişir (artar/azalır/değişmez)? Açıklayınız.

Bir öğrenci aşağıdaki cevabı verir:

"Sıcak su ve soğuk su karıştırıldığında hem sıcak suyun hem de soğuk suyun sıcaklığı değişir çünkü sıcak sudan soğuk suya sıcaklık geçişi olur. Bu iki suyun sıcaklığı eşitlenene kadar sıcak suyun sıcaklığı azalır ve soğuk suyun sıcaklığı artar."

Öğrencinin cevabında göze çarpan yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

8. Bir öğretmen, ısı ve sıcaklık konusuna başlarken öğrencilerin ön bilgisini ölçmek için aşağıdaki soruyu sorar.

Sıcak bir yaz günü Pelin kendisine bir bardak limonata doldurur ve içerisine buz ekler. Pelin, on dakika sonra buzların eridiğini ve limonatanın soğuduğunu fark eder. Sizce limonata nasıl soğumuş olabilir?

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

9. Bir fizik dersinde, yünlü giysilerin insanları neden sıcak tuttuğuyla ilgili sınıf tartışması yapılır. Öğretmen, öğrencilerden günlük hayatta karşılaştıkları benzer örnekler vermelerini ister. Bazı öğrencilerin verdiği örnekler şu şekildedir:

Elif: Dışarıda üşüyen ellerimizi kaloriferde ısıtırız.

Yeşim: Evimizdeki ısı kaybını önlemek için çift katlı pencereler kullanırız.

Efe: Soğuk içilen içecekler alüminyum şişede satılır.

Aynı soruyu sınıfınızda sorsaydınız, öğrencilerinizin verebileceği yanlış cevaplar hangi öğrenci ya da öğrenciler gibi olurdu?

Elif ( ) Yeşim ( ) Efe ( )

Öğrencilerinizin bu cevapları vermesine neden olan yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri yazınız.

10. Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar:

"Bir öğrenci yazın havuza girer. Bir kovaya havuz suyu doldurur ve sıcaklığını 25 °C olarak ölçer. Öğrenci, aynı termometreyle havuzdaki suyun sıcaklığını da 25 °C olarak ölçer. Öğrenci şu çıkarımda bulunur: 'Kovadaki ve havuzdaki suyun sıcaklığı aynı. Bu yüzden kovadaki ve havuzdaki suyun sahip oldukları ısı eşittir'. Öğrencinin yaptığı çıkarıma katılıyor musunuz?"

Öğrencilerin %75'i bu soruya "evet" cevabı verir.

Öğrencilerin bu cevabı vermelerine neden olan yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

11. Bir fizik dersinde öğrencilerden biri şu yorumda bulunur:

“Su ısıtıcısında kaynayan suyun iç enerjisi, buzluktaki buz küplerinin iç enerjisinden daha fazladır çünkü suyun sıcaklığı daha fazladır.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

12.

Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar ve gruplar halinde tartışmalarını ister.

“Kış mevsiminde bazı evlerin çatılarında buz sarkıtları oluşur. Sabahları güneş ışıkları buz sarkıtlarına vurmakta ve buz sarkıtları ısı almaktadır. Buz sarkıtlarında gerçekleşmesi muhtemel ve kesin değişiklikler neler olabilir?”

Öğretmen, öğrenci gruplarının verdiği cevapları tahtaya not eder:

Sarkıtlarda gerçekleşmesi kesin değişiklikler	Sarkıtlarda gerçekleşmesi muhtemel değişiklikler
-İç enerjisi artar. -Sıcaklığı artar. -Isısı artar.	-Yoğunluğu azalır. -Buz halden sıvı hale dönüşür.

Öğrencilerin verdiği cevaplarda dikkatinizi çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

2.BÖLÜM: Bu bölümde ısı-sıcaklık konusuyla ilgili öğretim yöntemlerine yönelik sorular bulunmaktadır.

1. Okulunuzda staj yapan bir fizik öğretmen adayı ders planı hazırlayacaktır. Öğretmen adayı dersi yanılgılı bir öğrenci düşüncesi üzerine kurgulamak ister: "Bütün metallerin öz ısıları aynıdır". Öğretmen adayı, tasarlayabileceği deneyler konusunda sizden fikir ister.

Öğretmen adayına önerebileceğiniz basit bir deney tasarlayınız.

Öğretmen adayının dersi yanılgılı düşünceler üzerine kurgulamasının sebepleri neler olabilir? Aklınıza gelen tüm fikirleri sıralayınız.

2. Bir fizik öğretmeni derste bir analoji (benzetme) kullanır:

Mısır patlatmak için bir tencereye mısır taneleri eklenir ve ocağın üstüne konur. Süre geçtikçe mısır taneleri tencere içinde hareket etmeye ve tencere kenarlarına çarpmaya başlar.

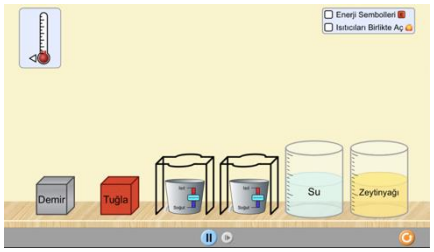
Fizik öğretmeni bu analojiyi (benzetmeyi) öncelikli olarak aşağıdaki büyüklüklerden hangisini açıklamak için kullanmış olabilir?

Öz ısı	
Sıcaklık	
Isı sığası	
Konveksiyon	

Bu analojinin (benzetmenin) sınırlılıkları ne olabilir?

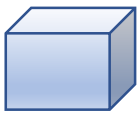
3. Bir fizik dersinde öğrenciler “90 °C sıcaklığındaki 250 g suyla 10 °C sıcaklığındaki 500 g su karıştırılırsa denge sıcaklığı ne olur?” sorusunu araştıracaktır. Bir öğrenci grubu gerçek laboratuvar malzemeleri kullanmaya karar verir (1. yöntem). Diğer bir grup ise sanal laboratuvar (simülasyon) kullanmayı tercih eder (2. yöntem).





Araştırma sorusu bağlamında düşündüğünüzde, 2. yöntemin 1. yönteme kıyasla sahip olduğu avantajlar neler olabilir?

4. Bir öğrenci, maddelerin soğuma hızının hacme ve yüzey alanına bağlı olduğunu düşünür ve bir deney tasarlar. Deneyde aynı ortamda bulunan su dolu iki farklı deponun soğuma hızlarını inceler.

	
Yüzey alanı=$6m^2$ Hacim=$2m^3$	Yüzey alanı=$5m^2$ Hacim=$3m^3$

Öğrencinin tasarladığı deneyde ihmal ettiği bilimsel uygulama özelliğini yazınız.

5. Fizik dersinde yapılabilecek deneylerden oluşan bir kitapta, aşağıdaki etkinlik önerisi yer almaktadır:

Boş bir cam şişenin ucuna balon takılır ve şişe geniş bir kaba yerleştirilir. Kaba sıcak su dökülür ve balonun zamanla şiştiği görülür.

Bu aktivite kitapta deney olarak adlandırılmıştır fakat gerçek bilimsel deney özelliklerini yansıtmamaktadır. Bunun sebebi ne olabilir? Aklınıza gelen tüm düşünceleri yazınız.

6. Bir fizik öğretmeni derste bir analoji (benzetme) kullanır:

İşçiler, kum torbalarını üst üste dizip bir duvar yaparlar. Bazı işçiler diğerlerinden daha dayanıklıdır; çok fazla yorulmadan uzun bir süre boyunca kum torbalarını taşıyıp duvar oluşturabilir. Bir kısım işçi ise çok hızlı çalışabilir. Fakat hızlı çalışıyor olmaları, uzun süre boyunca çalışabildikleri anlamına gelmez.

Fizik öğretmeni, kullandığı analojide kum torbalarından oluşan duvarı "tranfer edilen ısı"ya benzetmiştir. Bu örnekte benzetimi yapılan diğer büyüklükler aşağıdakilerden hangisi olabilir?

Öz ısı-İç enerji	
Isı sığası-İç enerji	
İç enerji-İletkenlik	
Isı sığası-İletkenlik	

7. Bir fizik öğretmeni öğrencilerine aşağıdaki aktiviteyi yaptırır.

Üç farklı kavanoza sıcak su, soğuk su ve oda sıcaklığında su konur. Kavanozlara birer damla gıda boyası damlatıldığında, sıcak sudaki boyanın soğuk sudaki boyaya göre daha hızlı yayıldığı görülür.

Öğretmen bu aktivite ile öğrencilerin hangi çıkarımı yapmasını istemiş olabilir?

8. Bir fizik öğretmeni derste şekildeki gösterimi yapar. Su ile dolu plastik bir kap içerisine mavi gıda boyası ile renklendirilmiş buz ve kırmızı gıda boyası ile renklendirilmiş sıcak su ekler ve öğrencilerden suyu gözlemlemelerini ister.



Şekil

Öğretmen bu gösterimi kullanarak aşağıdaki olayların hangilerini açıklamak istemiş olabilir? Birden fazla işaretleme yapabilirsiniz.

Magma sıvısının hareketi	
Donmuş etin çözünmesi	
Mumun yanması	
Sıcak hava balonlarının çalışması	
Mikrodalga fırının çalışması	
Meltem rüzgarlarının oluşması	
Soba yakılan bir odanın ısınması	

9. Bilişsel çelişki, kişilerin düşünceleri ile gerçek hayatta karşılaştıkları durumlar arasında var olan uyumsuzluktur.

Örnek: Öğrenciler soğuk bir kış gününde, parktaki metal ve tahta bankların sıcaklığını ölçer. Öğretmen, etkinlik sonrasında öğrencilerde bilişsel çelişki yaşandığını fark eder.

Aşağıdakilerden hangisi, bilişsel çelişki yaratmak isteyen bir öğretmenin kullanabileceği etkinliklerdendir? Birden fazla işaretleme yapabilirsiniz.

Bir buz parçasını yünle kaplayıp sıcaklık değişimini ölçmek	
İçerisine sıcak bir metal kaşık konulan suyun sıcaklık değişimini ölçmek	
0 °C'deki suya buz eklemek ve suyun sıcaklık değişimini ölçmek	
Donmuş zeytinyağı ve buzun erimeye başladıkları sıcaklıkları karşılaştırmak	

10. Bir fizik öğretmen adayı staj dersinde öğrencilere etkinlik yaptırmak ister. Isı iletimi konusuyla ilgili ilgi çekici bir etkinlik teması oluşturur ve aşağıdaki bilgilendirici metni hazırlar.

> Penguenleri kurtar!
>
> Kutuplarda yaşayan penguenler küresel ısınma tehdidiyle karşı karşıya. Penguenleri sıcaktan koruyacak evler yapmak istemez misin? Hadi penguenler için bir ev tasarlayalım!

Öğretmen adayı etkinlik kapsamında kullanılacak malzemeleri belirler: Buz parçaları, yün kumaş, termometre

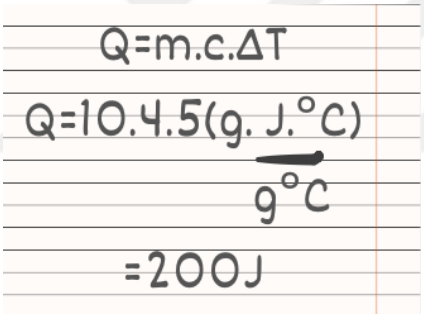
Öğretmen adayının hazırladığı bu etkinlik, bilimsel araştırma basamaklarına daha uygun olacak şekilde nasıl düzenlenebilir? Aklınıza gelen tüm önerileri yazınız.

11. Bir fizik öğretmeni bilimsel araştırma basamaklarını vurgulamak ister. Derste izlenecek adımlardan ve deneysel aşamalardan oluşan bir taslak hazırlar.

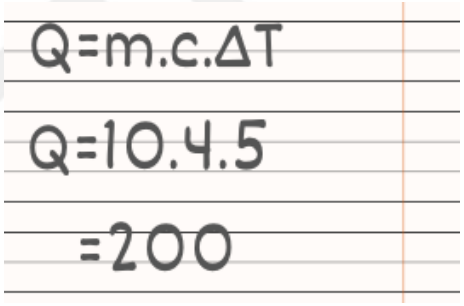
Aşağıdaki tabloda eksik olan ders içi adımları ve deneysel aşamaları tamamlayınız.

Ders İçi Adımlar	Deneysel Aşama
Soğuk bir kış gününde, alüminyumdan yapılmış bir bank, pirinçten yapılmış bir banka göre daha soğuk hissettirir.	Gözlem
Hangi materyal ısıyı daha iyi iletir?	(A)
(B)	Hipotez oluşturma
Isıl olarak yalıtılmış bir ortamda alüminyum ve pirinçten yapılmış iki farklı bardaktaki suya eşit miktarda ısı verilir.	(C)
İki bardaktaki suyun sıcaklık değişimi raporlanır ve grafik oluşturulur.	(D)
Alüminyum bardaktaki suyun sıcaklık değişimi, pirinç bardaktaki suyun sıcaklık değişiminden daha fazladır.	(E)

12. Aşağıda iki farklı öğrencinin soru çözümleri verilmiştir.



(Eren)



(Ali)

Eren'in soru çözüm şeklinin Ali'ye kıyasla ne gibi avantajları olabilir? Aklınıza gelen tüm fikirleri yazınız.

APPENDIX J

TABLE OF SPECIFICATIONS OF THE PCK-H&T TEST

Table J1. Table of Specifications for Knowledge of Student Understanding Dimension

		Items
Sub-topics	Heat and temperature	1, 5, 7, 10
	Heat conduction	2, 6, 9
	Change of state	12, 4
	Heat equilibrium	8
	Internal energy	9
	Thermometer	3
Alternative conceptions and difficulties	Substances possess heat.	1, 10, 12
	Temperature can flow.	1, 7
	Interal energy is a measure of total heat of a substance.	1
	Metals are insulators.	6, 9
	The temperature of any substance that is heated increases.	12
	Metals are cold.	2
	Temperature values can have multiples on the Celcius thermometer.	3
	Substances given the same amount of heat will have the same final temperature.	5
	Wool warms people.	6
	Internal energy depends only on temperature.	9

Table J2. Table of Specifications for Knowledge of Instructional Strategies Dimension

		Items
Sub-topics	Heat and temperature	3, 4, 9, 16, 17, 18, 19
	Heat conduction	2, 6, 7, 8, 11, 14
	Heat transfer	10, 15, 20
	Heat equilibrium	5
	Change of state	12, 13
	Specific heat	1
Instructional strategies	Experiment	1, 2, 9, 11, 17
	Direct instruction	16
	Unit	3
	Demonstration	6, 7, 8, 10, 12, 13, 15, 18, 19, 20
	Analogy	4, 14
	Simulation	5

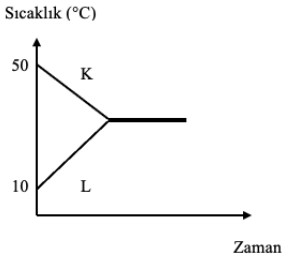
APPENDIX K

TEST ITEMS AND EXEMPLARY CLASSIFICATIONS OF RESPONSES

Knowledge of Student Understanding

KSU.1

A physics teacher asks her students to interpret the graph in the figure.



One of the students commented as follows: “Initially, the heat of object K is higher than the heat of object L. Since the heat of body K is higher, its internal energy is higher than L. Over time, there was a temperature transition from K to L, the temperature of K decreased, and the temperature of L increased."

What are the misconceptions that stand out in the student's comments?

Classification	Criteria
Correct (2)	All answers are given below: • Substances possess heat. • Internal energy is a measure of the total heat of a substance. • Temperature is a quantity that can be transmitted.
Partially correct (1)	Two or one of the following answers are given: • Matter has heat. • Internal energy is a measure of the total heat of a substance. • Temperature is a quantity that can be transmitted. • Heat and temperature are the same thing.
False/ irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.2

A physics teacher prepares the following question to identify students' misconceptions in a lesson on heat conduction.

"Ayşe and Ahmet clean the garden of their house on a cold winter day. While Ayşe uses a broom with a wooden handle, Ahmet uses a broom with a metal handle. While Ayşe is sweeping the garden without any problems, Ahmet feels his hands are cold. What could be the main reason why Ahmet feels this way?"

If you asked your students the same question, what would be the possible wrong answers your students could give to the question? List all the wrong answers that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The temperature of metal is lower than wood. • The specific heat of the metal is higher. • There was a coldness transfer from the metal to Mehmet's hand.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.3

A student interprets a heat-temperature graph as follows:

“When we examine the graph, we see that there is a relationship between the heat given to the substance and the temperature. As the amount of heat given to the mercury increases, the temperature of the mercury also increases. For example, while the temperature of mercury in the 1st second is 42 °C, it becomes 84 °C in the 5th second. In other words, the temperature in the fifth second is exactly twice the temperature in the first second.”

What might be the misconceptions that stand out in the student's comments? List all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • 84 °C is twice as high as 42 °C. • The temperature may be multiples of its magnitude.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.4

In a lesson where condensation is discussed, the teacher asks the students the following question.

“Some ice water is placed in a jar at room temperature. After 15 minutes, it is observed that the surroundings of the jar are wet. What is the reason for the wetness around the jar?”

What are the possible wrong answers that students can give to this question? List all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The jar has sweated. • Evaporation has occurred. • The jar gave off heat. • The ice melted and overflowed from the jar, wetting its surface. • Water leaked out of the small holes on the jar.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.5

A physics teacher asks his students the following discussion question.

Hilal takes out a bottle of juice and a bottle of soda from the refrigerator. She lets the bottles sit on the table for 20 minutes. Knowing that juice and soda bottles receive equal amounts of heat after twenty minutes, what quantities are exactly the same after that time? (A)Internal energy changes (B) Temperatures (C) Internal energies

What could be the misconceptions that might cause your students to give wrong answers?

Classification	Criteria
Correct (1)	The following answer is given: • When the same amount of heat is given to different substances, their final temperatures are the same. • Students had difficulty in applying the concept of heat capacity.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.6

Students heat water in two different glasses, foam and aluminum, and measure the temperature change of the water over time. Based on their findings, they explain which glass is more insulating and why. At the end of the experiment, the students were asked: "What material should be used to keep a soda bottle cold?" question is asked. Seventy-five of the students answer aluminum instead of foam.

What are the misconceptions of students who answer the question incorrectly?

Classification	Criteria
Correct (1)	One of the following answers is given: • Metals keep cold. • Metals are insulators. • Items that heat up quickly are also ideal for keeping them cold. • Aluminum is made of solid material. • They think that aluminum will keep them cold because they feel colder when they touch it. • Foam has a hollow structure and does not retain heat well.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.7

In a physics lesson where the subject of thermal equilibrium was discussed, the teacher asked the students the following question.

500 g of hot water at 80 degrees was mixed with 500 g of cold water at 40 degrees. How does the temperature of hot and cold water change (increase/decrease/remain unchanged)? Explain.

A student's answer to the question is as follows:

When hot water and cold water are mixed, the temperature of both hot water and cold water changes because there is a temperature transfer from hot water to cold water. The temperature of the hot water decreases and the temperature of the cold water increases until the temperature of these two waters becomes equal.

What is the misconception(s) that stands out in the student's answer?

Classification	Criteria
Correct (1)	The following answer is given: • There is a temperature transition between substances.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.8

A teacher asked the following question to measure students' prior knowledge when starting the topic of heat and temperature.

"On a hot summer day, Pelin pours herself a glass of lemonade and adds ice to it. After ten minutes, Pelin notices that the ice has melted and the lemonade has become cold. How do you think the lemonade could have gotten cold?

List possible wrong answers that students might give to this question.

Classification	Criteria
Correct (1)	The following answers are given: • Coldness has passed from ice to lemonade. • Ice gave its heat/temperature to lemonade • Lemonade's heat decreased/ice's temperature increased
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.9

In a class on heat conduction, a physics teacher gives a class discussion about why woolen clothes keep people warm. At the end of the discussion, students are asked to give similar examples they encounter in daily life. Some examples given by students are as follows:

Elif: We warm our hands when they are cold outside on the heater.

Barış: Car door handles are made of plastic to prevent damage in extremely cold weather.

Yeşim: We use double-storey windows to prevent heat loss in our home.

Efe: We cover hot foods with aluminum foil to prevent them from cooling quickly.

If you asked the same question in your class, which answer or answers would your students also give?

Elif	+
Barış	+
Yeşim	
Efe	+

What might be the misconceptions that cause your students to give these answers? Write down all the misconceptions that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • Woolen clothes gives heat. • Metals are insulators.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.10

In a physics lesson, the teacher asks her students the following question:

A student goes to the sea on a very hot summer day. He fills a bucket with sea water and measures its temperature as 16 degrees. The student also directly measures the temperature of sea water as 16 degrees with the same thermometer. As a result of his measurements, the student makes the following inference: "Since both water sources are at the same temperature, the heat energy they have is equal." Do you agree with the student's inference?

Seventy-five percent of the students answer "yes" to this question.

Write the misconception that caused the students to give this answer.

Classification	Criteria
Correct (2)	Aşağıdaki cevaplardan biri verilir: • Isı maddenin içsel özelliklerinden biridir. • Maddelerin ısısı vardır.
Partially correct (1)	At least two of the following answers are given: • He confused heat and temperature./Heat and temperature are the same thing. • He does not know that temperature does not depend on the amount of matter, but heat. • Failure to understand that heat is energy received and given. • He compared heat as he compared temperature. • Heat occurs when there is a temperature difference.
False/ irrelavant (0)	The following answer is given • He confused heat and temperature. • He confused heat and internal energy. / Heat and internal energy are the same thing. An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.11

In a physics class, one student comments as follows:

The internal energy of boiling water in the kettle is greater than the internal energy of ice cubes in the freezer because the temperature of the water is higher.

What is the problematic thought that stands out in the student's comment?

Classification	Criteria
Correct (1)	The following answers are given: • The student did not take into account mass, which is another variable on which internal energy depends. • The student thought that internal energy depends only on temperature.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

KSU.12

A physics teacher asks his students the following question and asks them to discuss it in groups.

During the winter, icicles form on the roofs of some houses. In the morning, sunlight hits the icicles, and the icicles receive heat. What are the possible and definite changes that will occur on the icicles?

At the end of the group discussions, the teacher notes the answers given by each student group on the board in two categories:

Changes that are likely to occur in the icicles	Changes that are certain to occur in the icicles
-Its density decreases. -It turns from ice to liquid.	Internal energy increases. -The temperature increases. -The heat increases.

What misconceptions do you notice in the answers given by students?

Classification	Criteria
Correct (2)	Two of the following answers are given: • The temperature of every substance that receives heat increases. • Substances possess heat.
Partially correct (1)	• One of the following answers is given: • The temperature of every substance that receives heat increases. • Substances possess heat.
False/ irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

Knowledge of instructional strategies

IS.1a

A physics teacher candidate who is doing an internship at your school will prepare a lesson plan. The teacher candidate wants to base the lesson on a mistaken student idea: "The specific heat of all metals is the same." The prospective teacher asks you for ideas about experiments he can design.

Design a simple experiment that you can recommend to a teacher candidate.

Classification	Criteria
Correct (1)	The following answer is given: • A simple experiment is designed to examine the change in temperature of two different metals depending on the heat given or received.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.1b

Öğretmen adayının dersi yanılgılı düşünceler üzerine kurgulamasının sebepleri neler olabilir? Aklınıza gelen tüm fikirleri sıralayınız.

Classification	Criteria
Correct (1)	Two of the following answers are given: • It enables students to connect their existing thoughts with new topics. • Students are surprised to discover that their thoughts are not correct and become ready to learn new information. • Students' misconceptions should be replaced with scientifically correct thoughts. • Student understandings are very difficult to change, but can be changed using good teaching methods. • Learning to recognize misconceptions through experience provides effective and permanent learning.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.2a

A physics teacher used the following analogy in his heat-temperature lesson: “To pop corn, corn kernels are added to a pot and placed on the stove. As time passes, the corn grains begin to move in the pot.”

Which of the following magnitudes can be explained by using this analogy?

Specific heat	
Temperature	+
Heat capacity	
Convection	

IS.2b

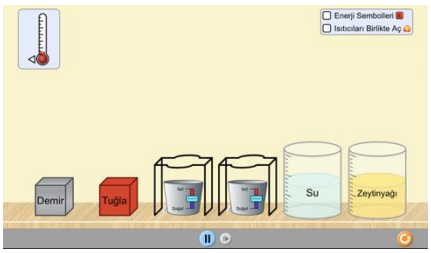
What could be the limitations of the analogy?

Classification	Criteria
Correct (1)	One of the following answers is given: • It cannot be used for phase change (during phase change, the temperature of the substance does not increase as it receives heat, but the movement of the heated corn accelerates). • Corn grains stop after a while, but the particles in the substance are in constant motion. • The structure of substances that receive heat and whose temperature increases does not change; in the analogy, the structure of corn that receives heat changes.
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.3

A physics teacher asked his students, "What will be the equilibrium temperature if 250 g of water at 90 °C is mixed with 500 g of water at 10 °C?". The teacher identifies two alternative methods for investigating the problem. In the first of these methods, real laboratory materials are used (Figure 1). In the second method, a virtual laboratory (simulation) is used (Figure 2).





When you think about it in the context of the question asked by the teacher, what advantages might the second method have over the first method?

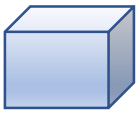
Classification	Criteria

Correct (1)	Aşağıdaki cevaplardan biri verilir:
	• Reducing the time required for thermal equilibrium to occur.
	• Ease of changing parameters
	  ○ Ability to work with very high and very low temperatures
	  ○ Being able to repeat the experiment for liquids at different temperaturesIsı yalıtım eksikliğinden vb. kaynaklanan karıştırıcı değişkenlerin etkisini engellemek
	• Safer and less risky as it does not work with high temperatures

False/Irrelevant (0)	An incorrect or irrelevant answer is given OR general answers are given without relating it to the experiment: • More trustworthy • Easier • Low risk • Provides more accurate results
Blank (0)	The question was left unanswered.

IS.4

A student thinks that the cooling rate of substances depends on volume and surface area and designs an experiment. In the experiment, he examines the cooling rates of the two different water tanks.

 Surface area = $6m^2$ Volume = $2m^3$	 Surface area = $5m^2$ Volume = $3m^3$

Write the feature of scientific application that the student neglected in the experiment he designed.

Classification	Criteria
Correct (1)	One of the following answers is given: • Two variables are examined simultaneously (volume and surface area); Only a single factor can be changed during an experiment and other variables must be kept constant. • The cooling rate in warehouses with different surface areas should be compared under equal conditions (in tanks with the same volume). • The cooling rate in tanks with different volumes should be compared under equal conditions (in tanks with the same surface area).
False/Irrelevant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.5

The following activity suggestion is included in a book consisting of experiments that can be done in physics class:

A balloon is attached to the end of an empty glass bottle and the bottle is placed in a large container. Hot water is poured into the container and the balloon is seen to inflate over time.

This activity is called an experiment in the book, but it does not reflect the characteristics of a real scientific experiment. What could be the reason for this? Write down all the thoughts that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers is given: • The effect of one variable on another variable is not measured and reported. • The experiment is not repeated with water at different temperatures.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.6

A physics teacher used the following analogy in his heat and temperature lesson: “Workers stack sandbags on top of each other and build a wall. Some workers are tougher than others. In other words, it can carry sandbags and create walls for a long time without getting too tired. Some workers can work very fast. But just because they work fast doesn't mean they can work for long periods of time.”

In the analogy he used, the physics teacher likened the wall made of sandbags to "transferred heat". Which of the following could be the other quantities simulated in this example?

Specific heat-Internal energy	
Heat capacity-Internal energy	
Internal energy-conductivity	
Heat capacity- conductivity	+

Classification	Criteria
Correct (1)	Only the “Heat capacity-Conductivity” option is selected.
False/Irrelevant (0)	An incorrect or irrelevant option is chosen.
Blank (0)	The question was left unanswered.

IS.7

A physics teacher made the following activity in his class.

Hot water, cold water and room temperature water are placed in three different jars. When a drop of food coloring is added to the jars, it is seen that the dye in hot water spreads faster than the dye in cold water.

What inference/conclusion might the teacher want the students to reach with this activity?

Classification	Criteria
Correct (1)	One of the following answers is given: • The speed of the particles of substances that receive heat increases. • When substances are hot, the speed of their particles is faster.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.8

A physics teacher makes the demonstration in the figure in class. He adds ice colored with blue food coloring and hot water colored with red food coloring into a plastic container filled with water and asks the students to observe the water.



Figure

Which of the following activities might the teacher have used this demonstration to explain?/ Which of the following events might the teacher have wanted to explain using this demonstration? You can make more than one mark.

Movement of magma fluid	+
Thawing frozen meat	+
Burning of candle	
Working of hot air balloons	+
Operation of the microwave oven	
Formation of breeze winds	+
Heating a room with a stove	+

Classification	Criteria
Correct (1)	Three, four or five correct choices were made.
False/Irrelevant (0)	Two, one or zero correct choices were made.
Blank (0)	The question was left unanswered.

IS.9

Cognitive disequlibrium is the incompatibility that exists between people's thoughts and the situations they encounter in real life.

Example:

In a physics class, students add ice to 0 degree water and note the temperature change of the water over time. The teacher notices that students experience cognitive dissonance after the activity.

Which of the following is an activity that a teacher who wants to use the cognitive equilibrium? You can make more than one mark.

Covering a piece of ice with wool and measuring the temperature change	+
Measuring the temperature change of water by placing a hot metal spoon into it	
Measuring the temperatures of metal and wooden benches in the park on a cold winter day	+
Comparing the temperatures at which frozen olive oil and ice begin to melt	

Classification	Criteria
Correct (2)	Not choosing 2. and 4. options AND Chopsing 1. and 3. options
Partially correct (1)	Not choosing 2. and 4. options AND Chopsing 1. or 3. options
False/Irrelevant (0)	Choosing one or two of the 2. and 4. options
BLANK (0)	The question was left unanswered.

IS.10

A physics teacher candidate wants to have students do an activity in his internship course. Creates an interesting activity theme on the topic of heat conduction and prepares the following informative text.

Save the penguins! Penguins living in the poles face the threat of global warming. Don't you want to build houses that will protect penguins from the heat? Let's design a house for penguins!

The teacher candidate determines the materials to be used within the scope of the activity: Ice pieces, wool fabric, thermometer.

How can this activity prepared by the teacher candidate be organized in a way that is more suitable for scientific research steps? Write down any suggestions that come to your mind.

Classification	Criteria
Correct (1)	Tthe following answer is given: • A control mechanism should be added to the experiment: A control variable or variables should be used to test which house type is more livable for penguins.
False/ irrelavant (0)	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.

IS.11

In a class where you cover heat conduction in solids, you want to emphasize the steps of scientific research. You have prepared an outline of the steps and experimental stages to be followed in the lesson.

Complete the missing in-course steps and experimental stages in the table below.

In-Class Steps	Experimental Phase
On a cold winter day, a bench made of aluminum feels colder than a bench made of brass.	Observation
Which material conducts heat better?	(A)
(B)	Hypothesis formation
Equal amounts of heat are given to water in two different glasses made of aluminum and brass.	(C)
The temperature change of the water in two glasses is reported and a graph is created.	(D)
The temperature change of water in an aluminum cup is greater than the temperature change of water in a brass cup.	(E)

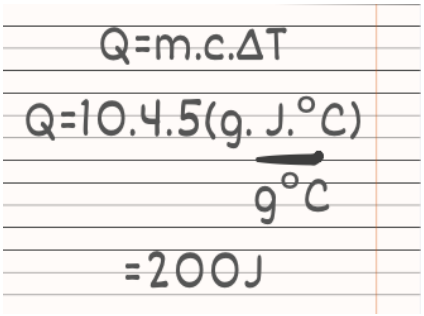
	Criteria		
Classification	(A)	(B)	(C)
Correct (1)	One of the following answers are given: • Formulating problem • Asking a research question	One of the following answers are given: • Aluminum conducts heat better than brass. • Aluminum is a better conductor.	One of the following answers are given: • Planning the experiment
False/ irrelavant (0)	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.	The question was left unanswered.	The question was left unanswered.

Classification	(D)	(E)
Correct (1)	One of the following answers are given: • Collecting data • Making measurements	One of the following answers are given: • Analysis of data • Evaluation • Result
False/ irrelavant (0)	An incorrect or irrelevant answer is given.	An incorrect or irrelevant answer is given.
Blank (0)	The question was left unanswered.	The question was left unanswered.

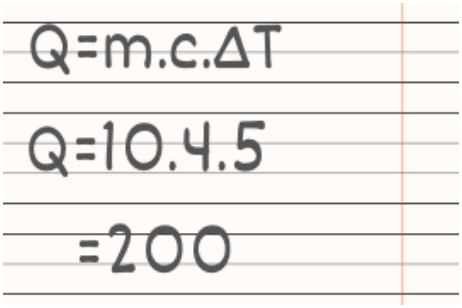
Classification schema		
		Classification
	5	Correct (2)
	4	Partially Correct (1)
	3	
	2	False/Irrelevant (0)
	1	
	0	

IS.12

Below are the solutions to questions from two different students.



(Eren)



(Ali)

What advantages do Eren's way of solving questions have compared to Ali? Write down all the ideas that come to your mind.

Classification	Criteria
Correct (1)	One of the following answers are given: • Numbers do not represent a physical magnitude on their own, they gain meaning with units. • Units make results understandable and meaningful. • Using units makes it easier to spot errors. • Constant use of units raises awareness of whether conversion is necessary before calculating. • Being accustomed to using units makes it easier to learn formulas and make connections (Kirschner et al., 2016).
False/Irrelevant (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Blank (0)	Soru cevapsız bırakıldı.

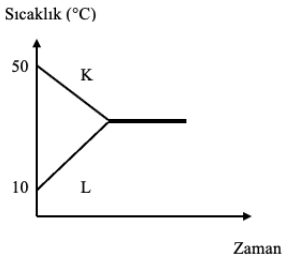
APPENDIX L

TURKISH VERSION OF TEST ITEMS AND EXEMPLARY CLASSIFICATIONS OF RESPONSES

Öğrenci Anlayışları Bilgisi

KSU.1

Bir fizik öğretmeni, öğrencilerinden şekildeki grafiği yorumlamasını ister.



Öğrencilerden biri şu yorumda bulunur: "Başlangıçta K cisminin ısısı, L cisminin ısısından daha fazladır. K cisminin ısısı daha fazla olduğu için iç enerjisi de L'den daha yüksektir. Zaman içerisinde K'dan L'ye sıcaklık geçişi olmuş, K'nın sıcaklığı düşmüş ve L'nin sıcaklığı yükselmiştir."

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevapların tamamı verilir: • Maddelerin ısısı vardır • İç enerji bir maddenin toplam ısısının ölçüsüdür • Sıcaklık iletilebilen bir büyüklüktür
Kısmen doğru (1)	Aşağıdaki cevaplardan ikisi ya da biri verilir: • Maddelerin ısısı vardır • İç enerji bir maddenin toplam ısısının ölçüsüdür • Sıcaklık iletilebilen bir büyüklüktür • Isı ve sıcaklık aynı şeydir
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.2

Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar.

“Ayşe ve Ahmet soğuk bir kış gününde evlerinin bahçesini temizler. Ayşe tahta saplı bir süpürge kullanırken, Ahmet metal saplı bir süpürge kullanır. Ayşe bahçeyi sorunsuz bir şekilde süpürürken, Ahmet ellerinin üşüdüğünü hisseder. Ahmet’in böyle hissetmesinin temel nedeni ne olabilir?”

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanlış cevapları sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Metalin sıcaklığı tahtadan daha düşüktür • Metalin öz ısısı daha yüksektir • Metalden Mehmet’in eline soğukluk geçişi olmuştur
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.3

Bir öğrenci ısı-sıcaklık grafiğini şöyle yorumlar:

“Maddeye verilen ısı ile maddenin sıcaklığı arasında bir ilişki var. Cıvaya verilen ısı miktarı arttıkça cıvanın sıcaklığı da artıyor. Örneğin 1. saniyedeki cıva sıcaklığı 42 °C iken 5. saniyede 84 °C oluyor. Yani dört saniye sonunda maddenin sıcaklığı iki katına çıkıyor.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • 84 °C, 42 °C nin iki katıdır. • Sıcaklık büyüklerinin katları olabilir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.4

Yoğunlaşma olayının işlendiği bir derste, öğretmen öğrencilere aşağıdaki soruyu sorar.

“Oda sıcaklığındaki bir kavanoz içerisine bir miktar buzlu su konur. 15 dakika sonra kavanozun etrafının ıslak olduğu gözlemlenir. Kavanozun etrafında ıslaklık oluşmasının sebebi nedir?”

Öğrencilerin bu soruya verebilecekleri muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Kavanoz terlemiştir • Buharlaşma yaşanmıştır • Kavanoz ısı vermiştir • Buz eriyip kavanozdan taşmış ve yüzeyini ıslatmıştır • Su kavanozun üzerindeki küçük deliklerden dışarıya sızmıştır
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.5

Bir fizik öğretmeni öğrencilerine aşağıdaki tartışma sorusunu sorar.

Hilal, buzdolabından bir şişe meyve suyu ve bir şişe soda çıkarır. Şişeleri masanın üzerinde 20 dakika boyunca bekletir. Meyve suyu ve soda şişelerinin yirmi dakika sonunda eşit miktarda ısı aldığı bilindiğine göre, bu süre sonunda hangi nicelikleri kesinlikle aynıdır? (B) İç enerji değişimleri (B) Sıcaklıkları (C) İç enerjileri

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevap şıkları neler olurdu?

A ( ) B ( ) C ( )

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • B, C ya da B&C şıkkı söylenir. • A şıkkı söylenmez.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğrencilerin yanlış cevap vermesine neden olabilecek yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Farklı maddelere aynı miktar ısı verildiğinde son sıcaklıkları aynı olur. • Öğrenciler ısı sığası kavramını uygulamakta zorluk yaşamıştır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.6

Öğrenciler bir fizik dersinde bir etkinlik yapar. Köpük ve alüminyum olmak üzere iki farklı bardağa su dökerler. Bardakları özdeş ısıtıcılarla ısıtıp zamanla bardaklardaki suların sıcaklık değişimini ölçerler. Bulguları doğrultusunda hangi bardağın daha iyi ısı yalıtımlı olduğunu açıklarlar.

Öğretmen deney sonunda öğrencilere şu soruyu sorar: "Bir sodayı soğuk tutmak için hangi malzemeden yapılmış bir kap kullanılmalıdır?" Öğrencilerin %75'i köpük yerine alüminyum cevabını verir.

Soruya yanlış cevap veren öğrencilerin yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Metaller soğuk tutar • Metaller yalıtkandır • Hızlı ısınan maddeler soğuk tutmak için de idealdir • Alüminyum sağlam malzemeden yapılmıştır/dayanıklıdır • Alüminyuma dokunduklarında daha soğuk hissettikleri için soğuk tutacağını düşünürler • Köpük boşluklu yapıdadır ve ısıyı iyi korumaz
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.7

Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar.

80 °C'deki 500 g sıcak suyla, 40 °C'deki 500 g soğuk su karıştırılmıştır. Sıcak ve soğuk suyun sıcaklığı nasıl değişir (artar/azalır/değişmez)? Açıklayınız.

Bir öğrenci aşağıdaki cevabı verir:

"Sıcak su ve soğuk su karıştırıldığında hem sıcak suyun hem de soğuk suyun sıcaklığı değişir çünkü sıcak sudan soğuk suya sıcaklık geçişi olur. Bu iki suyun sıcaklığı eşitlenene kadar sıcak suyun sıcaklığı azalır ve soğuk suyun sıcaklığı artar."

Öğrencinin cevabında göze çarpan yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Maddeler arasında sıcaklık geçişi olur (Sıcak sudan soğuk suya sıcaklık geçişi olur)
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.8

Bir öğretmen, ısı ve sıcaklık konusuna başlarken öğrencilerin ön bilgisini ölçmek için aşağıdaki soruyu sorar.

Sıcak bir yaz günü Pelin kendisine bir bardak limonata doldurur ve içerisine buz ekler. Pelin, on dakika sonra buzların eridiğini ve limonatanın soğuduğunu fark eder. Sizce limonata nasıl soğumuş olabilir?

Öğrencilerin bu soruya verebileceği muhtemel yanlış cevaplar neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplar verilir: • Muhtemel yanlış öğrenci cevapları: o Buzdan limonataya soğukluk/ısı geçmiştir o Buz ısısını/sıcaklığını limonataya verdi o Limonatanın ısısı azaldı/buzun ısısı arttı
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.9

Bir fizik dersinde, yünlü giysilerin insanları neden sıcak tuttuğuyla ilgili sınıf tartışması yapılır. Öğretmen, öğrencilerden günlük hayatta karşılaştıkları benzer örnekler vermelerini ister. Bazı öğrencilerin verdiği örnekler şu şekildedir:

Elif: Dışarıda üşüyen ellerimizi kaloriferde ısıtırız.

Yeşim: Evimizdeki ısı kaybını önlemek için çift katlı pencereler kullanırız.

Efe: Soğuk içilen içecekler alüminyum şişede satılır.

Aynı soruyu sınıfınızda sorsaydınız, öğrencilerinizin verebileceği yanlış cevaplar hangi öğrenci ya da öğrenciler gibi olurdu?

Elif	+
Barış	+
Yeşim	
Efe	+

Öğrencilerinizin bu cevapları vermesine neden olan yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Yünlü giysiler insanı ısıtır. • Metaller yalıtkandır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.10

Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar:

“Bir öğrenci yazın havuza girer. Bir kovaya havuz suyu doldurur ve sıcaklığını 25 °C olarak ölçer. Öğrenci, aynı termometreyle havuzdaki suyun sıcaklığını da 25 °C olarak ölçer. Öğrenci şu çıkarımda bulunur: ‘Kovadaki ve havuzdaki suyun sıcaklığı aynı. Bu yüzden kovadaki ve havuzdaki suyun sahip oldukları ısı eşittir’. Öğrencinin yaptığı çıkarıma katılıyor musunuz?”

Öğrencilerin %75’i bu soruya “evet” cevabı verir.

Öğrencilerin bu cevabı vermelerine neden olan yanılgılı düşünceleri neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevaplardan biri verilir: • Isı maddenin içsel özelliklerinden biridir. • Maddelerin ısısı vardır.
Kısmen doğru (1)	Aşağıdaki cevapların en az ikisi verilir: • Isı ve sıcaklığı birbirine karıştırmıştır./Isı sıcaklık aynı şeydir. • Sıcaklığın madde miktarına bağlı olmadığını, ısının bağlı olduğunu bilmiyordur. • Isının alınan verilen enerji olduğunu kavrayamaması • Sıcaklık karşılaştırır gibi ısı karşılaştırmıştır. • Isı, sıcaklık farkı olunca ortaya çıkar.
Yanlış/İlgisiz (0)	Aşağıdaki cevap verilir • Isı ve sıcaklığı birbirine karıştırmıştır. • Isı ve iç enerjiyi birbirine karıştırmıştır. / Isı iç enerji aynı şeydir. Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.11

Bir fizik dersinde öğrencilerden biri şu yorumda bulunur:

“Su ısıtıcısında kaynayan suyun iç enerjisi, buzluktaki buz küplerinin iç enerjisinden daha fazladır çünkü suyun sıcaklığı daha fazladır.”

Öğrencinin yorumunda dikkat çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplar verilir: • Öğrenci, iç enerjinin bağlı olduğu diğer bir değişken olan kütleyi dikkate almamıştır. • Öğrenci iç enerjinin yalnızca sıcaklığa bağlı olduğunu düşünmüştür.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

KSU.12

Bir fizik öğretmeni öğrencilere aşağıdaki soruyu sorar ve gruplar halinde tartışmalarını ister.

“Kış mevsiminde bazı evlerin çatılarında buz sarkıtları oluşur. Sabahları güneş ışıkları buz sarkıtlarına vurmakta ve buz sarkıtları ısı almaktadır. Buz sarkıtlarında gerçekleşmesi muhtemel ve kesin değişiklikler neler olabilir?”

Öğretmen, öğrenci gruplarının verdiği cevapları tahtaya not eder:

Sarkıtlarda gerçekleşmesi kesin değişiklikler	Sarkıtlarda gerçekleşmesi muhtemel değişiklikler
-İç enerjisi artar. -Sıcaklığı artar. -Isısı artar.	-Yoğunluğu azalır. -Buz halden sıvı hale dönüşür.

Öğrencilerin verdiği cevaplarda dikkatinizi çeken yanılgılı düşünceler neler olabilir? Aklınıza gelen tüm yanılgılı düşünceleri sıralayınız.

Kodlama	Kriter
Doğru (2)	Aşağıdaki cevaplardan ikisi verilir: • Isı alan her maddenin sıcaklığı artar. • Maddelerin ısısı vardır.
Kısmen doğru (1)	Aşağıdaki cevaplardan biri verilir: • Isı alan her maddenin sıcaklığı artar. • Maddelerin ısısı vardır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

Öğretim Stratejileri Bilgisi

IS.1a

Okulunuzda staj yapan bir fizik öğretmen adayı ders planı hazırlayacaktır. Öğretmen adayı dersi yanılgılı bir öğrenci düşüncesi üzerine kurgulamak ister: "Bütün metallerin öz ısıları aynıdır". Öğretmen adayı, tasarlayabileceği deneyler konusunda sizden fikir ister.

Öğretmen adayına önerebileceğiniz basit bir deney tasarlayınız.

Kodlama	Kriter
Doğru (1)	• İki farklı metalin verilen ya da alınan ısıya bağlı olarak sıcaklıklarının değişiminin incelendiği basit bir deney tasarlanır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.1b

Öğretmen adayının dersi yanılgılı düşünceler üzerine kurgulamasının sebepleri neler olabilir? Aklınıza gelen tüm fikirleri sıralayınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Öğrencilerin var olan düşünceleri yeni konularla bağlantı kurmayı sağlar. • Öğrenciler düşüncelerinin doğru olmadığını keşfedip şaşırır ve yeni bilgiler öğrenmeye hazır hale gelir • Öğrencilerin yanılgılı düşünceleri bilimsel olarak doğru düşüncelerle değiştirilmelidir. • Öğrenci anlayışlarının değiştirilmesi çok zordur, iyi öğretim yöntemleri kullanılarak değiştirilebilir • Kavram yanılgılarını deneyimleyerek fark etmek öğrenmek etkili ve kalıcı öğrenme sağlar.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.2a

Bir fizik öğretmeni derste bir analoji (benzetme) kullanır:

Mısır patlatmak için bir tencereye mısır taneleri eklenir ve ocağın üstüne konur. Süre geçtikçe mısır taneleri tencere içinde hareket etmeye ve tencere kenarlarına çarpmaya başlar.

Fizik öğretmeni bu analojiyi (benzetmeyi) öncelikli olarak aşağıdaki büyüklüklerden hangisini açıklamak için kullanmış olabilir?

Öz ısı	
Sıcaklık	+
Isı sığası	
Konveksiyon	

IS.2b

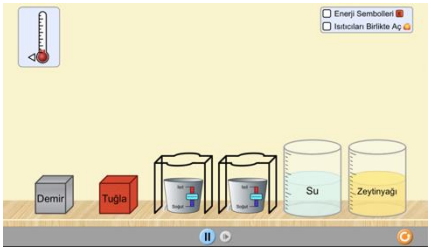
Bu analojinin (benzetmenin) sınırlılıkları ne olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Hal değişimi için kullanılamaz (Hal değişimi sırasında madde ısı alırken sıcaklığı artmaz ama ısınan mısırların hareketi hızlanır). • Mısır taneleri bir süre sonra durur fakat madde içerisindeki tanecikler sürekli hareket halindedir. • Isı alan ve sıcaklığı artan maddelerin yapısı değişmez, analojide ısı alan mısırın yapısı değişiyor.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.3

Bir fizik dersinde öğrenciler “90 °C sıcaklığındaki 250 g suyla 10 °C sıcaklığındaki 500 g su karıştırılırsa denge sıcaklığı ne olur?” sorusunu araştıracaktır. Bir öğrenci grubu gerçek laboratuvar malzemeleri kullanmaya karar verir (1. yöntem). Diğer bir grup ise sanal laboratuvar (simülasyon) kullanmayı tercih eder (2. yöntem).





Araştırma sorusu bağlamında düşündüğünüzde, 2. yöntemin 1. yönteme kıyasla sahip olduğu avantajlar neler olabilir?

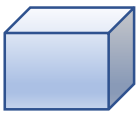
Kodlama	Kriter

Doğru (1)	Aşağıdaki cevaplardan biri verilir:
	• Isıl dengenin gerçekleşmesi için gereken süreyi azaltmak
	• Parametreleri değiştirme kolaylığı
	  ○ Çok yüksek ve çok düşük sıcaklıklarla çalışabilmek
	  ○ Deneyi farklı sıcaklıktaki sıvılar için tekrarlayabilmek
	• Isı yalıtım eksikliğinden vb. kaynaklanan karıştırıcı değişkenlerin etkisini engellemek
	• Yüksek sıcaklıklarla çalışılmadığı için daha güvenli ve daha az riskli

Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir YA DA deneyle ilişkilendirmeden genel cevaplar verilir: • Daha güvenli • Daha kolay • Az risk • Daha doğru sonuçlar verir
Boş (0)	Soru cevapsız bırakıldı.

IS.4

Bir öğrenci, maddelerin soğuma hızının hacme ve yüzey alanına bağlı olduğunu düşünür ve bir deney tasarlar. Deneyde aynı ortamda bulunan su dolu iki farklı deponun soğuma hızlarını inceler.

 Yüzey alanı=6m^2 Hacim=2m^3	 Yüzey alanı=5m^2 Hacim=3m^3

Öğrencinin tasarladığı deneyde ihmal ettiği bilimsel uygulama özelliğini yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • İki değişken aynı anda inceleniyor (hacim ve yüzey alanı); bir deney sırasında yalnızca tek bir faktör değiştirilebilir ve diğer değişkenler sabit tutulmalıdır. • Farklı yüzey alanına sahip depolardaki soğuma hızı eşit şartlar altında (aynı hacme sahip depolarda) karşılaştırılmalıdır. • Farklı hacme sahip depolardaki soğuma hızı eşit şartlar altında (aynı yüzey alanına sahip depolarda) karşılaştırılmalıdır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.5

Fizik dersinde yapılabilecek deneylerden oluşan bir kitapta, aşağıdaki etkinlik önerisi yer almaktadır:

Boş bir cam şişenin ucuna balon takılır ve şişe geniş bir kaba yerleştirilir. Kaba sıcak su dökülür ve balonun zamanla şiştiği görülür.

Bu aktivite kitapta deney olarak adlandırılmıştır fakat gerçek bilimsel deney özelliklerini yansıtmamaktadır. Bunun sebebi ne olabilir? Aklınıza gelen tüm düşünceleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Bir değişkenin diğer değişken üzerindeki etkisi ölçülmüyor ve raporlanmıyor. • Deney farklı sıcaklıklardaki su ile tekrarlanmıyor.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.6

Bir fizik öğretmeni derste bir analoji (benzetme) kullanır:

İşçiler, kum torbalarını üst üste dizip bir duvar yaparlar. Bazı işçiler diğerlerinden daha dayanıklıdır; çok fazla yorulmadan uzun bir süre boyunca kum torbalarını taşıyıp duvar oluşturabilir. Bir kısım işçi ise çok hızlı çalışabilir. Fakat hızlı çalışıyor olmaları, uzun süre boyunca çalışabildikleri anlamına gelmez.

Fizik öğretmeni, kullandığı analojide kum torbalarından oluşan duvarı "tranfer edilen ısı"ya benzetmiştir. Bu örnekte benzetimi yapılan diğer büyüklükler aşağıdakilerden hangisi olabilir?

Öz ısı-İç enerji	
Isı sığası-İç enerji	
İç enerji-İletkenlik	
Isı sığası-İletkenlik	+

Kodlama	Kriter
Doğru (1)	Yalnızca "Isı sığası-İletkenlik" seçeneği işaretlenir.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.7

Bir fizik öğretmeni öğrencilerine aşağıdaki aktiviteyi yaptırır.

Üç farklı kavanoza sıcak su, soğuk su ve oda sıcaklığında su konur. Kavanozlara birer damla gıda boyası damlatıldığında, sıcak sudaki boyanın soğuk sudaki boyaya göre daha hızlı yayıldığı görülür.

Öğretmen bu aktivite ile öğrencilerin hangi çıkarımı yapmasını istemiş olabilir?

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Isı alan maddelerin taneciklerinin hızı artar. • Maddeler sıcakken taneciklerinin hızı daha fazladır.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.8

Bir fizik öğretmeni derste şekildeki gösterimi yapar. Su ile dolu plastik bir kap içerisine mavi gıda boyası ile renklendirilmiş buz ve kırmızı gıda boyası ile renklendirilmiş sıcak su ekler ve öğrencilerden suyu gözlemlemelerini ister.



Şekil

Öğretmen bu gösterimi kullanarak aşağıdaki olayların hangilerini açıklamak istemiş olabilir? Birden fazla işaretleme yapabilirsiniz.

Magma sıvısının hareketi	+
Donmuş etin çözünmesi	+
Mumun yanması	
Sıcak hava balonlarının çalışması	+
Mikrodalga fırının çalışması	
Meltem rüzgarlarının oluşması	+
Soba yakılan bir odanın ısınması	+

Kodlama	Kriter
Doğru (1)	3, 4 ya da 5 doğru seçim yapılmıştır.
Yanlış/İlgisiz (0)	2, 1 ya da 0 doğru seçim yapılmıştır.
Boş (0)	Soru cevapsız bırakıldı.

IS.9

Bilişsel çelişki, kişilerin düşünceleri ile gerçek hayatta karşılaştıkları durumlar arasında var olan uyumsuzluktur.

Örnek: Öğrenciler soğuk bir kış gününde, parktaki metal ve tahta bankların sıcaklığını ölçer. Öğretmen, etkinlik sonrasında öğrencilerde bilişsel çelişki yaşandığını fark eder.

Aşağıdakilerden hangisi, bilişsel çelişki yaratmak isteyen bir öğretmenin kullanabileceği etkinliklerdendir? Birden fazla işaretleme yapabilirsiniz.

1. Bir buz parçasını yünle kaplayıp sıcaklık değişimini ölçmek	+
2. İçerisine sıcak bir metal kaşık konulan suyun sıcaklık değişimini ölçmek	
3. 0 °C'deki suya buz eklemek ve suyun sıcaklık değişimini ölçmek	+
4. Donmuş zeytinyağı ve buzun erimeye başladıkları sıcaklıkları karşılaştırmak	

Kodlama	Kriter
Doğru (2)	2. ve 4. seçenekleri işaretlememek VE 1. ve 3. seçenekleri işaretlemek
Kısmen doğru (1)	2. ve 4. seçenekleri işaretlememek VE 1. ya da 3. seçenekleri işaretlemek
Yanlış/İlgisiz (0)	2. ya da 4. seçeneklerden birini ya da ikisini işaretlemek.
Boş (0)	Soru cevapsız bırakıldı.

IS.10

Bir fizik öğretmen adayı staj dersinde öğrencilere etkinlik yaptırmak ister. Isı iletimi konusuyla ilgili ilgi çekici bir etkinlik teması oluşturur ve aşağıdaki bilgilendirici metni hazırlar.

Penguenleri kurtar! Kutuplarda yaşayan penguenler küresel ısınma tehdidiyle karşı karşıya. Penguenleri sıcaktan koruyacak evler yapmak istemez misin? Hadi penguenler için bir ev tasarlayalım!

Öğretmen adayı etkinlik kapsamında kullanılacak malzemeleri belirler: Buz parçaları, yün kumaş, termometre

Öğretmen adayının hazırladığı bu etkinlik, bilimsel araştırma basamaklarına daha uygun olacak şekilde nasıl düzenlenebilir? Aklınıza gelen tüm önerileri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan birisi verilir: • Deneye kontrol mekanizması eklenmeli: Hangi ev türünün penguenler için daha yaşanılır olduğunu test etmek amacıyla kontrol değişkeni ya da değişkenleri kullanılmalı.
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

IS.11

Bir fizik öğretmeni bilimsel araştırma basamaklarını vurgulamak ister. Derste izlenecek adımlardan ve deneysel aşamalardan oluşan bir taslak hazırlar.

Aşağıdaki tabloda eksik olan ders içi adımları ve deneysel aşamaları tamamlayınız.

Ders İçi Adımlar	Deneysel Aşama
Soğuk bir kış gününde, alüminyumdan yapılmış bir bank, pirinçten yapılmış bir banka göre daha soğuk hissettirir.	Gözlem
Hangi materyal ısıyı daha iyi iletir?	(A)
(B)	Hipotez oluşturma
Isıl olarak yalıtılmış bir ortamda alüminyum ve pirinçten yapılmış iki farklı bardaktaki suya eşit miktarda ısı verilir.	(C)
İki bardaktaki suyun sıcaklık değişimi raporlanır ve grafik oluşturulur.	(D)
Alüminyum bardaktaki suyun sıcaklık değişimi, pirinç bardaktaki suyun sıcaklık değişiminden daha fazladır.	(E)

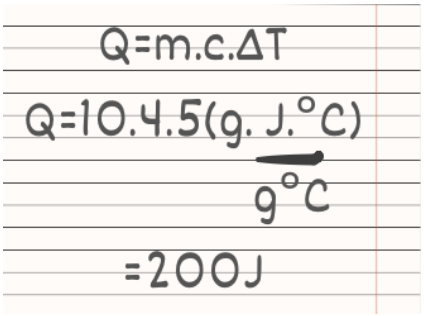
Kodlama	Kriter		
	(A)	(B)	(C)
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Problem oluşturma • Araştırma sorusu sorma	Aşağıdaki cevaplardan biri verilir: • Alüminyum ısıyı pirinçten daha iyi iletir. • Alüminyum daha iyi bir iletkendir.	Aşağıdaki cevaplardan biri verilir: • Deney planlama • Deney
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.	Yanlış ya da ilişkisiz bir cevap verilir.	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.

Kodlama		
	(D)	(E)
Doğru (1)	Aşağıdaki cevaplardan biri verilir: • Veri toplama • Ölçüm yapma	Aşağıdaki cevaplardan biri verilir: • Veri analizi • Verileri değerlendirme • Değerlendirme • Sonuç
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.	Soru cevapsız bırakıldı.

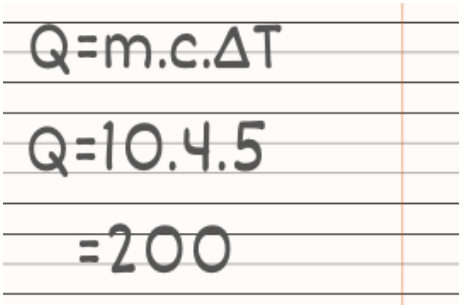
		Kodlama
Puan	5	Doğru (2)
	4	Kısmen doğru (1)
	3	
	2	Yanlış/İlgisiz (0)
	1	
	0	

IS.12

Aşağıda iki farklı öğrencinin soru çözümleri verilmiştir.



(Eren)



(Ali)

Eren'in soru çözüm şeklinin Ali'ye kıyasla ne gibi avantajları olabilir? Aklınıza gelen tüm fikirleri yazınız.

Kodlama	Kriter
Doğru (1)	Aşağıdaki cevaplardan ikisi verilir: • Sayılar tek başlarını fiziksel bir büyüklük ifade etmezler, birimle anlam kazanırlar. • Birimler sonuçları anlaşılır ve anlamlı kılar. • Birim kullanmak hataları fark etmeyi kolaylaştırır. • Birimleri sürekli kullanmak hesaplama yapmadan önce dönüştürme yapmaya gerek olup olmadığı konusunda farkındalık uyandırır. • Birimleri kullanmaya alışkın olmak formülleri öğrenmeyi ve bağlantılar kurmayı kolaylaştırır (Kirschner et al., 2016).
Yanlış/İlgisiz (0)	Yanlış ya da ilişkisiz bir cevap verilir.
Boş (0)	Soru cevapsız bırakıldı.

APPENDIX M

ETHICAL APPROVAL FROM MINISTRY OF NATIONAL EDUCATION

Boğaziçi Üniversitesi Evrak Tarih ve Sayısı: 10.03.2023-117155

T.C.
MİLLÎ EĞİTİM BAKANLIĞI
Strateji Geliştirme Başkanlığı

Sayı : E-49614598-605.01-71820822 08.03.2023
Konu : Araştırma Uygulama İzin Talebi

DAĞITIM YERLERİNE

İlgi: a) Bakanlığımızın 21/01/2020 tarihli ve 2020/2 No.lu Araştırma Uygulama İzinleri Genelgesi.
b) Boğaziçi Üniversitesi Rektörlüğünün 06/03/2023 tarihli ve E-60914867-199-115696 sayılı yazısı.

Boğaziçi Üniversitesi, Sosyal Bilimler Enstitüsü Öğrenme Bilimleri Doktora Programı öğrencisi Havva SAĞLAM'ın, "Fizik Öğretmenlerinin Pedagojik Alan Bilgisini Ölçen Bir Ölçek Geliştirme Çalışması" konulu çalışmasına veri sağlamak amacıyla anket çalışması yapma izin talebine ilişkin ilgi (b) yazı ve ekleri Bakanlığımız tarafından incelenmiştir.

Bakanlığımıza bağlı resmi/özel okul ve kurumlarda öğretmenlerin katılımıyla deneme modeli olarak yapılması planlanan uygulamanın denetimi il/ilçe millî eğitim müdürlükleri ve okul/kurum idaresinde olmak üzere, kurum faaliyetlerini aksatmadan, gönüllülük esasına göre; onaylı bir örneği Bakanlığımızda muhafaza edilen ve uygulama sırasında da mühürlü ve imzalı örnekten çoğaltılan, veri toplama araçlarının uygulanmasına ve sadece ekte imzalı formları bulunan öğretmelerin anket çalışmalarının ses kaydının alınmasına ilgi (a) Genelge doğrultusunda izin verilmiştir.

Gereğini bilgilerinize rica ederim.

Mehmet Fatih LEBLEBİCİ
Bakan a.
Başkan

Ek:
1-Onaylı Veri Toplama Araçları (16 Sayfa)
2-Ayse Başvuru (2 Sayfa)
3-Form (16 Sayfa)

Dağıtım:
Gereği:
B Planı

Bilgi:
Boğaziçi Üniversitesi Rektörlüğüne

Bu belge güvenli elektronik imza ile imzalanmıştır.
Adres : Milli Eğitim Bakanlığı 4/A
Belge Doğrulama Adresi : https://www.turkiye.gov.tr/meb-ebys
Bilgi için: Fatma TABALU
Telefon No : 0 (312) 413 27 51
Unvan : Şube Müdürü
E-Posta: sgb_arastirmaizinleri@meb.gov.tr
İnternet Adresi: www.sgb.gov.tr
Faks:3124186401
Kep Adresi : meb@hs01.kep.tr
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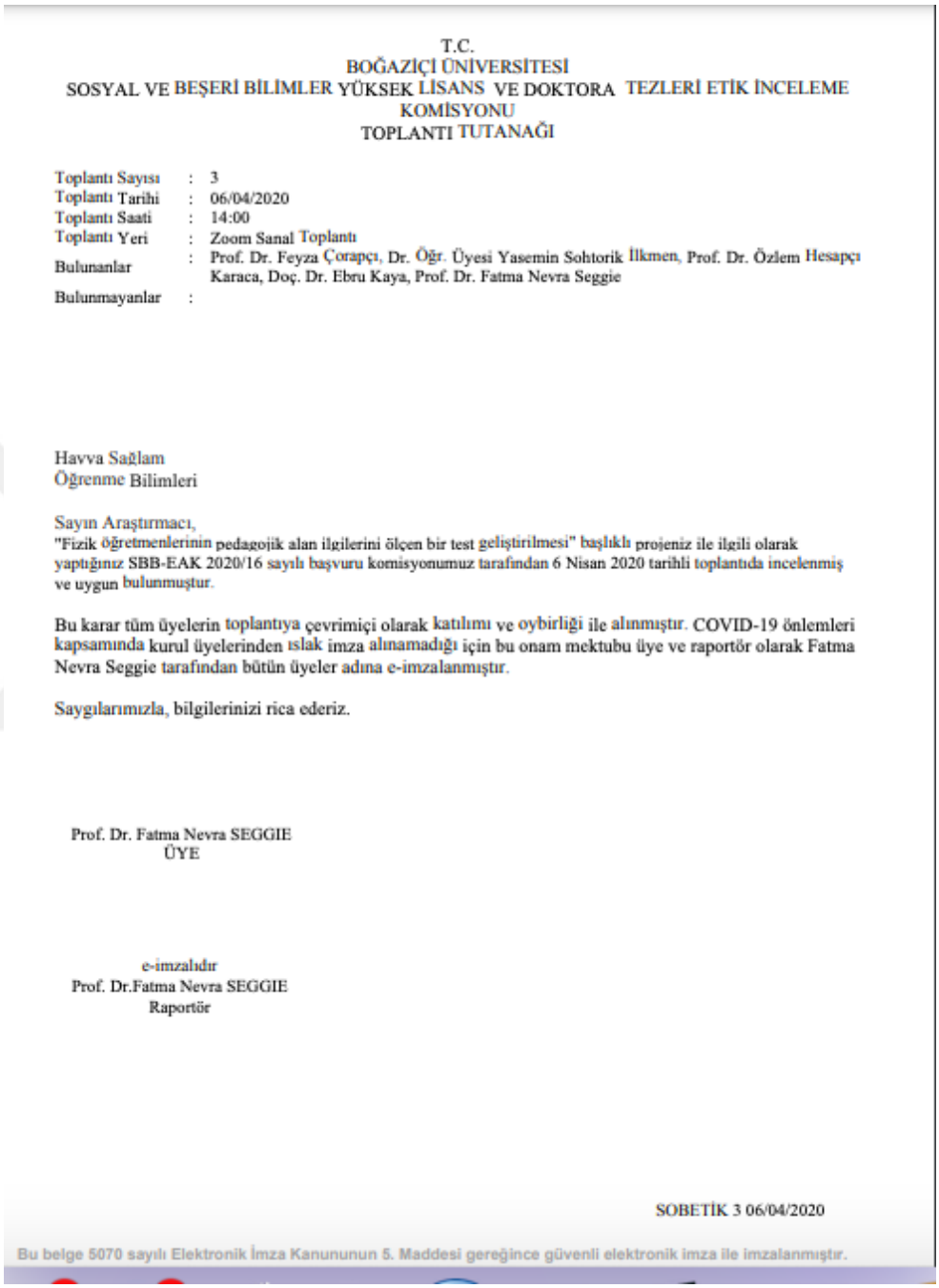
APPENDIX N

ETHICAL APPROVAL FROM BOĞAZİÇİ UNIVERSITY



T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI TUTANAĞI

Toplantı Sayısı : 3
Toplantı Tarihi : 06/04/2020
Toplantı Saati : 14:00
Toplantı Yeri : Zoom Sanal Toplantı
Bulunanlar : Prof. Dr. Feyza Çorapçı, Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen, Prof. Dr. Özlem Hesapçı Karaca, Doç. Dr. Ebru Kaya, Prof. Dr. Fatma Nevra Seggie
Bulunmayanlar :

Havva Sağlam
Öğrenme Bilimleri

Sayın Araştırmacı,
"Fizik öğretmenlerinin pedagojik alan ilgilerini ölçen bir test geliştirilmesi" başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2020/16 sayılı başvuru komisyonumuz tarafından 6 Nisan 2020 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya çevrimiçi olarak katılımı ve oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onam mektubu üye ve raportör olarak Fatma Nevra Seggie tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Prof. Dr. Fatma Nevra SEGGIE
ÜYE

e-imzalıdır
Prof. Dr.Fatma Nevra SEGGIE
Raportör

SOBETİK 3 06/04/2020

Bu belge 5070 sayılı Elektronik İmza Kanununun 5. Maddesi gereğince güvenli elektronik imza ile imzalanmıştır.

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